TWR-17830 (Rev B)

SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Ultrasonic Bolt Gage Qualification (PDX 934-01) Final Test Report

Revision B

July 1989

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-30490
DR No. 5-3
WBS No. HQ301-10-10
ECS No. 02265

Thiokol CORPORATION
SPACE OPERATIONS

P.O. Box 707, Brigham City, UT 84302-0707 (801) 863-3511

Publications No. 89343

(NASA-CR-183726) ULTRASONIC BOLT GAGE QUALIFICATION (PDX-934-01), REVISION B Final Test Report (Thiokol Chemical Corp.) 80 p

N90-70085

Unclas
00/37 0224758

Ultrasonic Bolt Gage Qualification (PDX 934-01)
Final Test Report

Revision B

Prepared by:

Test Planning and Reporting

Nondestructive Engineering

Approved by:

Test Planning and Reporting
Supervisor

Program Manager

Project Engineer

System Safety

Reliability

Data Management
ECS No. 02265

REVISION DESCRIPTION

REV LTR	DATE	DESCRIPTION
Basic	Jan 1988	
A	Feb 1989	TWR-17830 was the final report for a test conducted per CTP-0044 to satisfy the requirements for qualification of the PDX 934-01 Ultrasonic Boltmaster® Bolt Gage. The objective of the test was to demonstrate the ability of the bolt gage to consistently achieve a preload scatter within 10 percent of target preload. The test was successful. Additional objectives for qualification of the bolt gage were then defined and further tests conducted between January and June of 1988 per CTP-0044, Revision A. All objectives were met. This report addresses these additional objectives.
B	July 1989	Revision B changes must be incorporated into the document to make it complete. Revisions are marked in the text by a vertical bar in the right-hand margin. Section 3, APPLICABLE DOCUMENTS Add: TWR-17830 Ultrasonic Bolt Gage Qualification (PDX 934-01) Final Test Report (Basic) STW7-3437A Nozzle-to-Case Radial and Axial Bolts Instrumentation and Removal CTP-0044 Qualification Test Plan for Use of the PDX 934-01 Boltmaster® Bolt Gage <u>Drawings</u> 7U50878 NJAD Aft Dome - Insulated 7U50877 NJAD Fixed Housing - Insulated Paragraph 5d, <u>October 1987</u> Was: CTP-044 Now: CTP-0044

REVISION DESCRIPTION

REV LTR	DATE	DESCRIPTION
B	July 1989	Paragraph 5.2.2, <u>Mechanical Length Measurements at Known Tensile Loads</u> Was: 1.375-in.-dia load collar Now: 1.375-in.-dia load collar (Appendix A) Was: Tensile machine adapter tooling Now: Tensile machine adapter tooling (Appendix A) Was: Threaded hole fixture (portion of aft dome with access to foot of bolt) Now: Threaded 8-hole aft dome fixture (portion of aft dome with access to foot of bolt) (Appendix A) Was: "C" fixture to mount micrometer and steel post Now: "C" fixture to mount micrometer and steel post (Appendix A) Was: Heavy-duty photo stand with crossbeam Now: Heavy-duty photo stand with crossbeam (Appendix A) Paragraph 5.2.3, <u>Strainsert and Ultrasonic Bolt Load Reading Comparison</u> Was: 0.875-in.-dia load collar 1.375-in.-dia load collar Now: 0.875-in.-dia load collar (Appendix A) 1.375-in.-dia load collar (Appendix A) Was: Tensile machine adapter tooling for both radial and axial bolts Now: Tensile machine adapter tooling for both radial and axial bolts (Appendix A) Paragraph 5.2.4, <u>Nozzle Bolt Calibrations</u> Was: Tensile machine 0.875-in. load collar 1.375-in. load collar Now: Baldwin tensile machine 0.875-in. load collar (Appendix A) 1.375-in. load collar (Appendix A)

REVISION DESCRIPTION

REV LTR	DATE	DESCRIPTION
B	July 1989	Was: Tensile machine adapter tooling for radial and axial bolts 0.875-in. and 1.375-in. threaded hole plates Now: Tensile machine adapter tooling for radial and axial bolts (Appendix A) 0.875-in. cross bolt and 1.375-in. axial bolt threaded hole plates (Appendix A) Paragraph 5.2.5, <u>Torque Comparison of Ultrasonic and Strainsert Bolts in NJAD</u> Was: <u>Test hardware</u>: NJAD aft dome NJAD fixed housing Ten 1U75167-04 bolts Ten 1U76034-02 bolts Ten 1U75311-03 bolts Ten 1U75311-05 bolts PDX 934-01 bolt gage PDX 769 axial transducer PDX 770 radial transducer Minidas Strainsert monitor <u>Test Fixtures</u>: 3,000 ft-lb torque wrench 600 ft-lb torque wrench Now: <u>Test hardware</u>: NJAD aft dome (Drawing 7U50878) NJAD fixed housing (Drawing 7U50877) Ten 1U75167-04 bolts Ten 1U76034-02 bolts Ten 1U75311-03 bolts Ten 1U75311-05 bolts PDX 934-01 bolt gage PDX 769 axial transducer PDX 770 radial transducer Minidas Strainsert monitor 3,000 ft-lb torque wrench 600 ft-lb torque wrench

REVISION DESCRIPTION

REV LTR	DATE	DESCRIPTION
B	July 1989	Add: RSRM-BLT-100C for bolt gage setup and signal setup was followed. The NJAD aft dome and fixed housing were assembled according to Drawings 7U50878 and 7U50877, respectively. Paragraph 5.2.6, <u>Ultrasonic Load Versus Grip Length</u> Was: Tensile machine adapter tooling for axial bolts Now: Tensile machine adapter tooling for axial bolts (Appendix A) Add: Appendix A, TEST HARDWARE ILLUSTRATIONS

ACTIVE PAGE RECORD

PAGE NO.	REVISION	PAGE NO.	REVISION	PAGE NO.	REVISION	PAGE NO.	REVISION
1-4	A						
5	B						
6-13	A						
14	B						
15	A						
16	B						
17-29	A						
30	B						
31-50	A						
51	B						
52-53	A						
54	B						
55-56	A						
57	B						
58-60	A						
A-1 - A-9	B						

ABSTRACT

Calibration work on the nozzle radial and axial bolts has evolved from work on a load collar with some generic transducers to work on a tensile machine in specially designed fixtures with specially made transducers. This document relates the history of the calibration work on the nozzle bolts and provides detailed test reports on the work done to date. All objectives were met and the Boltmaster® was qualified for use on RSRM nozzle-to-case joint radial and axial bolts.

During assembly of TPTA-2.0 on 4 Jan 1988, there was a large discrepancy between the torque required to load the ultrasonic bolts and that required to load the Strainsert bolts. A special team was set up to investigate this discrepancy. The following tests were performed:

a. Mechanical length measurements at known tensile load in load collar and tensile machine.

b. Comparison of Strainsert load readings to ultrasonic load readings in load collar and tensile machine.

c. Recalibration of bolts in tensile machine.

d. Torque comparison of ultrasonic and Strainsert bolts in NJAD.

e. Grip length test in tensile machine.

Sufficient documentation exists to repeat any of the tests.

CONTENTS

FIGURES

TABLES

1

INTRODUCTION

1.1 HISTORICAL BACKGROUND

A test was conducted per CTP-0044 to satisfy the requirements for qualification of the PDX 934-01 Ultrasonic Boltmaster® Bolt Gage. The objective of the test was to demonstrate that the bolt gage was capable of consistently achieving a preload scatter within 10 percent of target preload. The test was successful and the results are documented in TWR-17830. Additional objectives for qualification of the bolt gage were then defined and further tests conducted between January and June 1988 per CTP-0044, Revision A. Sufficient documentation exists to repeat any of the tests. All objectives were met and the Boltmaster® was qualified for use on RSRM nozzle-to-case joint radial and axial bolts. This report addresses these additional objectives.

1.2 DEFINITIONS

To understand the mathematics of this paper the following needs to be defined:

a. Stress Factor (SF): a unitless value between 0 and 1 that is multiplied by the ultrasonic elongation reading to compensate for a reduction in material velocity as stress is increased in the fastener.

b. Load Factor (LF): a number which defines the slope of the line that relates elongation to load. Units are in lb/in. This slope is equivalent to the slope of the elastic portion of a stress strain curve for the fastener material.

c. Y-intercept (Y): a Y offset for the load factor. Units are in lb.

d. Initial Length (L1): the ultrasonic initial length of the fastener. This number may vary slightly from the actual mechanical length; however, the way it is used compensates for any error in L1 or L2.

e. Loaded Length (L2): the ultrasonic length of the fastener after a load has been applied.

f. Raw Elongation: this is (L2 - L1). Since this number reflects the effects of the slowing down of the ultrasonic signal due to stress in the bolt, it will be much larger than the actual elongation.

g. Actual Elongation: this is (L2 - L1) x SF. This number reflects a theoretical elongation value for a given load in the fastener.

These numbers are used in a slope-intercept equation of form $y = mx + b$ to determine actual load in the fastener: load = LF x ((L2 - L1) x SF) + Y

1.3 TEST OVERVIEW

A brief history of the test process is as follows:

a. 25 to 30 Jun 1987. Calibrations for the radial and axial bolts were generated at Raymond Engineering Inc. (REI) for the sole purpose of learning the method so that calibration work could be done at Morton Thiokol.

b. July and August 1987. General lab work was done.

c. September 1987. Calibration factors for the radial bolt were generated at Morton Thiokol.

d. October 1987. A qualification study was run to determine the relative accuracy of ultrasonics as compared to torque (CTP-0044 and TWR-17830). Acceptance testing was done to officially determine the calibration values for the axial bolts (P/N 1U76034-01).

e. December 1987. The axial bolt load collar cracked on 3 Dec 1987. Multiple calibrations were made on the load collar; however, no data from test runs exist.

f. January 1988. During assembly of TPTA-2.0 on 4 Jan 1988, there was a large discrepancy between the torque required to load the ultrasonic bolts and that required to load the Strainsert bolts. A special team was set up to investigate this discrepancy. The following tests were performed:

   1. Mechanical length measurements at the known tensile load in the load collar and tensile machine.

2. Comparison of Strainsert load readings to ultrasonic load readings in the load collar and tensile machine.

3. Recalibration of bolts in the tensile machine.

4. Torque comparison of ultrasonic and Strainsert bolts in NJAD.

2

OBJECTIVES

Test objectives were derived to satisfy the requirements of CPW1-3600A, paragraph 4.4.1.5 and CDW2-3356, paragraph 3.2.1.1. The objectives of this test are as follows:

a. Certify the PDX 934-01 Boltmaster® bolt gage operation and inspection procedures for use on RSRM nozzle-to-case joint radial and axial bolts.

b. Certify the calibration methods and materials used with the PDX 934-01 Boltmaster® bolt gage.

c. Certify that the PDX 934-01 Boltmaster® gage interfaces with RSRM components without damage to equipment or hardware.

d. Demonstrate that the PDX 934-01 Boltmaster® bolt gage is capable of consistently achieving a preload scatter within 10 percent of the target preload.

3

APPLICABLE DOCUMENTS

The latest revision of the following documents, unless otherwise specified, is applicable to the extent specified herein.

Reference	Title
TWR-10161	Quality Plan for Space Shuttle Solid Rocket Motor Project
TWR-10163	Safety Plan for Space Shuttle Solid Rocket Motor Project
TWR-17830	Ultrasonic Bolt Gage Qualification (PDX 934-01) Final Test Report (Basic)
RSRM-BLT-100C	Use of the PDX 934-01 Smart Receiver Ultrasonic Bolt Gage
CDW2-3356	Identification Item Specification: Part I, Performance, Design and Verification Requirements, Ultrasonic Bolt Preload Analyzer Kit Model Designator, C77-0483, Space Shuttle Solid Rocket Motor Project
STW7-3437A	Nozzle-to-Case Radial and Axial Bolts Instrumentation and Removal
CPW1-3600A	Contract End Item Specification
CTP-0044	Qualification Test Plan for Use of the PDX 934-01 Boltmaster Bolt Gage
MIL-STD-45662	Calibration System Requirements
P/N 1U75167	Bolt, Machine
P/N 1U76034	Bolt, Case/Nozzle
P/N 1U75311	Instrumented Bolt (Strainsert)
Drawings	
7U50878	NJAD Aft Dome - Insulated
7U50877	NJAD Fixed Housing - Insulated

4

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY OF TEST RESULTS

4.1.1 Torque Versus Preload

This information is presented in detail in TWR-17830.

4.1.2 Mechanical Length Measurements at Known Tensile Loads

a. Summary. The intent of this test was to quantify and assign the error found between pure tensile loading of axial bolts in a tensile machine and tensile/torsion of the bolts in a load collar. Analysis of calibration procedures showed that the method of calibrating the Boltmaster® assumed two things: 1) the speed of an ultrasonic signal is not affected by torsion, and 2) the load collar load reading is not affected by torsion. Since a difference existed in the two processes, one of these assumptions could not be true. Testing was conducted between 29 Mar and 6 Apr 1988 to build a traceable data path for calibration of the Boltmaster® ultrasonic bolt gage and prove which of the above assumptions was not true.

b. Conclusions. The data show that the load collar requires an elongation of 13 percent less than the tensile machine. If the bolt is stretching less, the load must truly be less. Therefore, the load collar is affected by the variation between its calibration and its use. The major difference between calibration and use is that the load collar is calibrated in pure compression and then used in compression/torsion. This difference probably accounts for the majority of the error. Test data from a comparison between the load collar and the tensile machine, using Strainsert bolts as a constant datum, showed the same 13-percent error, supporting the conclusion that the error is due entirely to the load collar.

c. Recommendations. Since the data show that the tensile machine is the most accurate way to calibrate to load, all future calibration work should be done in it. Because the load collar reads consistently 13 percent lower than the tensile machine, data should be adjusted by the 13-percent correction factor.

Further work should be done to determine the effect of torsion on the load collar. The testing done here has only been able to state that the load collar is affected by the difference between calibration and actual use. Torsion is the most likely suspect, but there are other possible places for error.

4.1.3 Strainsert and Ultrasonic Bolt Load Reading Comparison

a. Summary. The purpose of this test was to determine the best method of ultrasonically calibrating the bolts so that they are equivalent to Strainsert bolts when torqued into a nozzle joint.

b. Conclusions. The data show that the Strainsert bolts agree very well with the tensile machine. The ultrasonic axial bolts need a small adjustment to read closer to the tensile machine, while the ultrasonic radial bolts require a somewhat larger adjustment.

c. Recommendations. Since the Strainsert bolts and the tensile machine are calibrated and they agree, all future calibration work should be done specifically on the tensile machine.

There is some discrepancy in the amount of error between Strainsert and ultrasonic bolts in the two loading methods (tensile machine and load collar). One hypothesis is as follows:

> The process of torquing a bolt into a load collar causes a higher load reading at any given actual load than if the load collar is loaded in pure compression in a tensile machine. If a Strainsert bolt has the same type of effect, then a Strainsert would show a higher load reading when torqued than when loaded in pure tension. If a Strainsert bolt were torqued into a load collar, then at a given load the Strainsert would read higher, closing in on the load collar reading. This would reduce the amount of error seen between the Strainsert and the load collar.

When the data are interpreted according to the above hypothesis, it is possible that the Strainsert bolts are in error by as much as 6 percent on the axial bolt and 10 percent on the radial bolts. This is an area for further study.

4.1.4 Nozzle Bolt Calibrations

a. Summary. This test is designed to determine and verify the calibration factors (stress factor, load factor, and Y-intercept) for each bolt type. These calibration factors are used to determine the load in the bolt based on stretch.

b. Conclusions. Regardless of the number of different slopes, the output load value for each of the four curves has a fairly tight scatter (Figure 4.1.4-1), meaning that the theoretical elongation value chosen for the test can be arbitrary as long as the slope is adjusted to compensate.

c. Recommendations. In order to achieve the smallest error, a conservative data point closest to the center of the Y axis scatter band should be chosen as the most correct, and the corresponding calibration values should be used for all axial bolt work.

For the radial bolts, the largest and most accurate data base is that performed on the tensile machine at Morton Thiokol (Figure 4.1.4-2).

4.1.5 Torque Comparison of Ultrasonic and Strainsert Bolts

a. Summary. The test determined the difference in accuracy between the bolt gage and the instrumented bolts. Testing was performed on the NJAD-3 test article. Ultrasonic and vendor-instrumented load data were taken during NJAD-3 assembly at specified torque/load values.

b. Conclusions. The test was not a large enough sample to draw conclusions, but the data indicate that the axial bolts are being loaded equally with both the ultrasonics and Strainserts.

c. Recommendations. There are no recommendations for changing calibration or procedure, but this test substantiates the quality of the new axial bolt calibration data.

Test	No. Bolts	No. Data Pts/Bolts
1	6	5
2	3	9
3	3	6
4	3	10
5	10	8

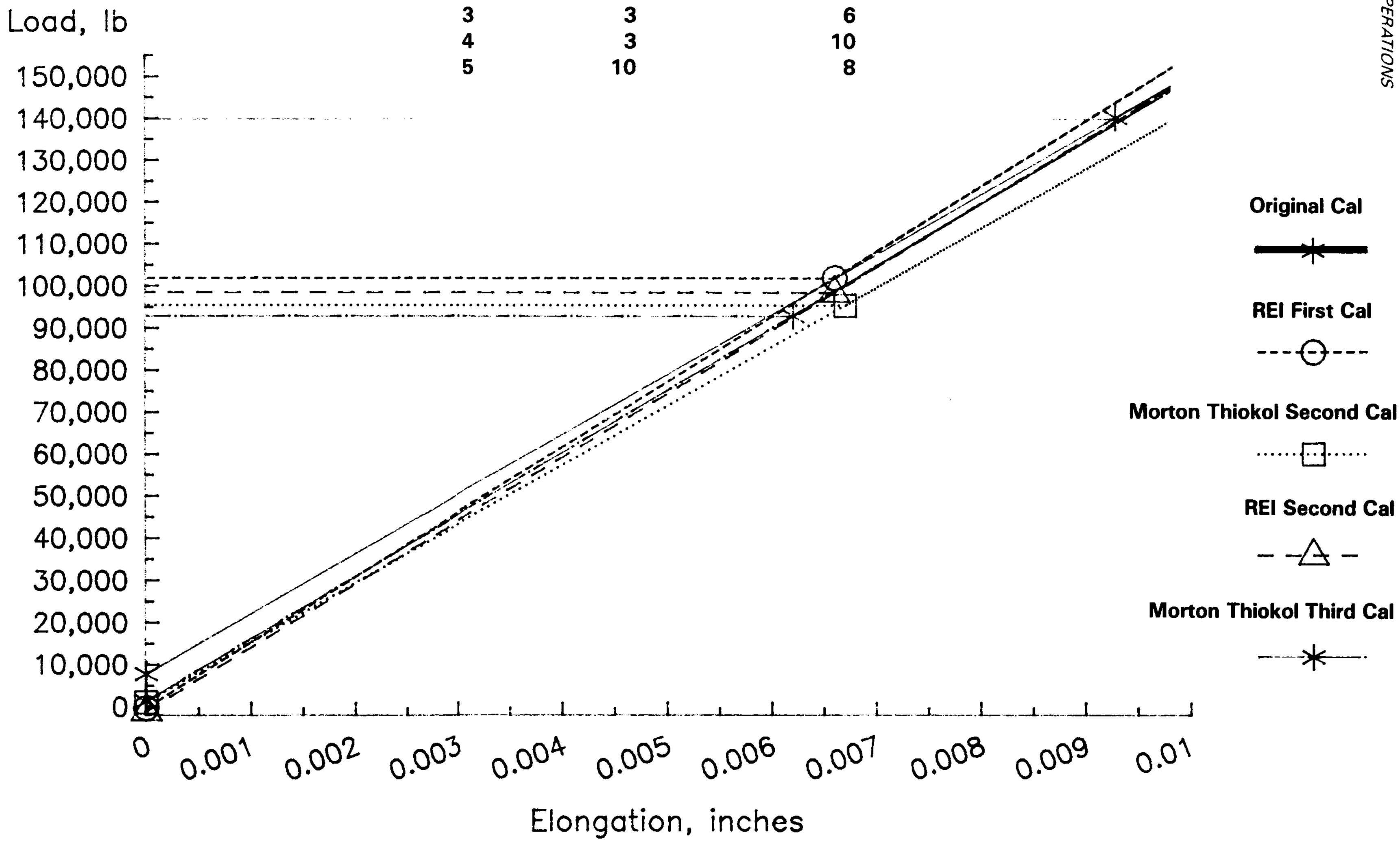


Figure 4.1.4-1. Determination of Axial Bolt Factors, Test 3A

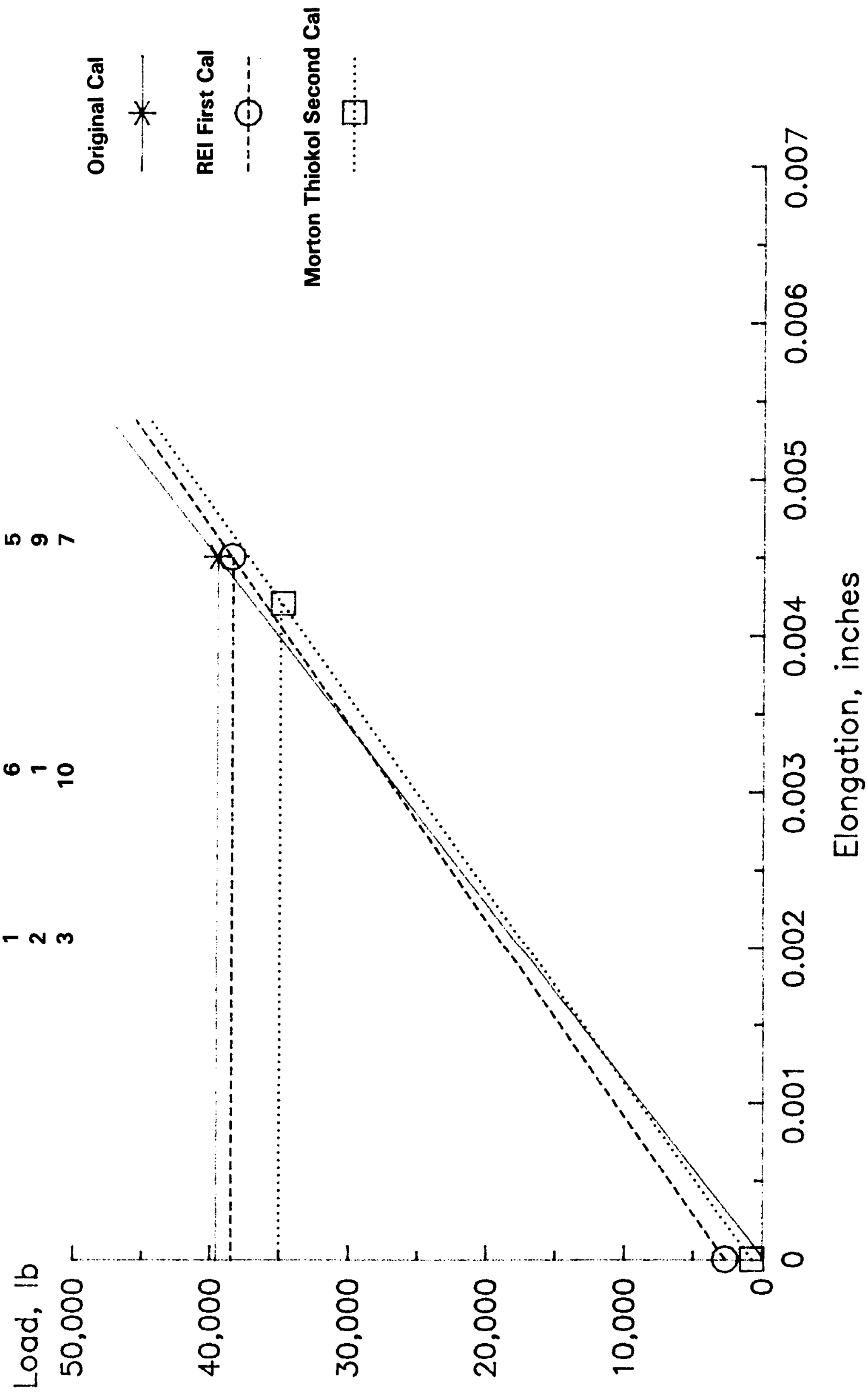


Figure 4.1.4-2. Determination of Radial Bolt Factors, Test 3B

4.1.6 Ultrasonic Load Versus Grip Length

a. Summary. The intent of this test was to determine whether or not there is a change in accuracy of the bolt gage when the bolt grip length changes. To test the effect of changing grip lengths, bolts were repeatedly loaded to a constant load with increasing grip lengths and their ultrasonic elongations read.

b. Conclusions. The data showed that the ultrasonics were not as dependent on grip length to determine elongation as theory predicted. Therefore, the accuracy of the bolt gage is not compromised, regardless of the change in bolt length.

c. Recommendations. The bolt gage should continue to be used without any modification or compensation for changes in grip length.

4.2 CONCLUSIONS

A summary of conclusions made from the test results as they relate to the test objectives is as follows. The section where the results are discussed in detail is also referenced.

Objective	Result
Certify the PDX 934-01 Boltmaster® bolt gage operation and inspection procedures for use on RSRM nozzle-to-case joint radial and axial bolts.	Testing was done to certify Boltmaster® bolt gage operation and inspection procedures for use on RSRM nozzle-to-case joint radial and axial bolts. (Section 5.2)
Certify the calibration methods and materials used with the PDX 934-01 Boltmaster® bolt gage.	Testing was conducted to build a traceable data path for calibration of the Boltmaster® ultrasonic bolt gage. (Section 5.2)
Certify the PDX 934-01 Boltmaster® bolt gage interfaces with RSRM components without damage to equipment or hardware.	No damage to equipment or hardware resulted from the use of the Boltmaster® gage. (Section 5.2)

Objective (Cont)

Demonstrate that the PDX 934-01 Boltmaster® bolt gage is capable of consistently achieving a preload scatter within 10 percent of the target preload.

Result (Cont)

The Boltmaster® ultrasonic preload measuring instrument showed only small percentage deviation from bolt to bolt in both radial and axial bolt tests. The average percentage deviation is 6.2 percent for radial bolts and 3.57 percent for axial bolts, which is well within the 10-percent target for preload scatter. (TWR-17830)

CEI Specification Paragraph 4.4.1.5
Support Equipment Certification

All support equipment shall undergo certification tests as a part of the configuration inspection. Certification shall include interface and functional testing on both radial and axial bolts. Qualification proof load testing is not applicable.

The ultrasonic Boltmaster® has been certified through interface and functional testing on both radial and axial bolts. Qualification proof load tests are not applicable. (Section 5.2)

CDW2-3356 Paragraph 3.2.1.1

General Performance. This device provides a means of measuring RSRM nozzle-to-case bolt preload during and after installation. The unit will be required to support installation on plant and at launch site. The use of this device shall not affect the reusability requirements of CPW1-3600, Table IV (nozzle bolts should be capable of 19 uses).

The ultrasonic Boltmaster® has been proven to support installation of RSRM nozzle-to-case bolts during and after installation. The use of the Boltmaster® does not affect reusability requirements of CPW1-3600, Table IV. (Section 5.2)

5

RESULTS

5.1 TEST PROCESS HISTORY

a. <u>25 to 30 Jun 1987</u>. Three 78545-22H-24 bolts (old style axial) and one 1U75167-01 bolt (short radial) were taken to REI. This was the first work done on ultrasonic preload analysis equipment for Morton Thiokol. Calibrations were generated there for the radial and axial bolts for the sole purpose of learning the method so that calibration work could be done here at Morton Thiokol.

Calibration factors generated at REI are:

Bolt P/N	Stress Factor	Load Factor (lb/in.)	Y-intercept (lb)
78545-2211-24	0.328	1.55 E7	-3,160
1U75167-01	0.448	7.968 E6	2,677

It should be noted that the 78545-22H-24 bolt had a concave head, and was tested using a convex, rubber-faced transducer. Very little faith was put into this reading because it was not known what changes to expect when the bolt was modified to have a flat inside the head rather than a concave, as well as changing to a ceramic-faced transducer.

b. <u>July and August 1987</u>. General work was done in the lab. Because an undersized transducer in a load collar was being used, it was necessary to remove and replace the transducer. Very few meaningful results were produced.

c. <u>September 1987</u>. The radial transducers were received. Work was done to develop calibration factors for the radial bolt at Morton Thiokol. Remove and replace errors were making it difficult to repeat calibrations on different radial bolts. Jeff Plocharczyk from REI came to Morton Thiokol to help with calibration. Using a modified wrench, repeatable calibrations were generated as follows:

Bolt P/N	Stress Factor	Load Factor (lb/in.)	Y-intercept (lb)
1U75167-02	0.448	8.839 E6	-161

These calibration factors generate a load value 4 percent higher than the calibration factors initially generated at REI.

d. October 1987. The axial transducer was received. A qualification study was run to determine the relative accuracy of ultrasonics as compared to torque (CTP-0044 and TWR-17830). The testing was done in a load collar, and both the load and scatter were compared.

A major problem with the axial bolt calibration began at this point. Apparently, an improperly calibrated load collar was used for these tests. The calibration was low by approximately 30 percent.

The ultrasonic bolt gage was calibrated by using the 0.328 SF generated at REI. Then the LF and Y-intercept were calculated using the load collar. The LF used was 3.119 E7 lb/in. and the Y-intercept was 14,922 lb. These values require much less elongation to achieve load. A comparison of these with the values generated at REI, given 0.006 in. actual elongation in the bolt, shows:

REI load: 89,840 lb
Morton Thiokol load: 142,062 lb

If we assume that the REI value is closest to actual (further testing proved that this was the case), then the Morton Thiokol calibration values were 58 percent above actual. In comparison, the REI value is 37 percent lower than the Morton Thiokol value.

Acceptance testing was done to officially determine the calibration values for the axial bolt, P/N 1U76034-01. In this test the entire calibration procedure was performed, which included determining a stress factor. A theoretical stretch for a 140,000-lb load was determined to be 0.0093 inch. A bolt was loaded to 140,000 lb in a load collar; then the stress factor on the bolt gage was adjusted so that the bolt gage display read a 0.0093-in. elongation. The other factors were then calculated.

Stress Factor: 0.464
Load Factor: 1.425 E7 lb/in.
Y-intercept: 7,750 lb

To compare these calibration factors to the ones determined for the qualification test, it is necessary to begin with a raw elongation value:

Given (L2 - L1) = 0.0183
REI: 89,840 lb
Morton Thiokol Qualification Load: 142,062 lb
Morton Thiokol Acceptance Load: 128,750 lb

The Morton Thiokol qualification load value is approximately 10 percent higher than the Morton Thiokol acceptance load value. The Morton Thiokol acceptance values have been used for all static and flight motors through June 1988.

e. December 1987. The axial bolt load collar cracked on 3 Dec 1987. Multiple calibrations were made on the load collar; however, no data from test runs exist.

f. January 1988. During assembly of TPTA-2.0 on 4 Jan 1988, there was a large discrepancy between the torque required to load the ultrasonic bolts and that required to load the Strainsert bolts. A test was done on two axial Strainsert bolts in the laboratory to compare the Strainsert readings to the load collar readings. The load variation between Strainsert and load collar was 40 percent, the same as the variation between torques on the ultrasonics and Strainserts. Note that this is very close to the 37-percent difference seen between the REI and Morton Thiokol load values shown in the qualification data taken in October.

The Minidas was checked for calibration, and was correct within 1.2 percent.

A special team was set up to investigate this discrepancy. The following tests were performed:

1. Mechanical length measurements at known tensile load in load collar and tensile machine.

2. Comparison of Strainsert load readings to ultrasonic load readings in load collar and tensile machine.

3. Recalibration of bolts in tensile machine.

4. Torque comparison of ultrasonic and Strainsert bolts in NJAD.

5. Grip length test in tensile machine.

5.2 TEST RESULTS

5.2.1 Torque Versus Preload

5.2.2 Mechanical Length Measurements at Known Tensile Loads

A listing of the test equipment, lot conditions, and testing procedures is as follows:

Test Hardware:

1.375-in.-dia load collar (Appendix A)
Voltage output monitor
Dial micrometer, 0.0001 accuracy
Baldwin tensile machine
PDX 934-01 bolt gage
PDX 769 axial bolt transducer
Three 1U76034-01 bolts

Test Fixtures:

Tensile machine adapter tooling (Appendix A)
Six 0.5-in.-dia steel balls
Urethane glue
Threaded 8-hole aft dome fixture (portion of aft dome with access to foot of bolt) (Appendix A)
Sphere and steel post
"C" fixture to mount micrometer and steel post (Appendix A)
Heavy-duty photo stand with crossbeam (Appendix A)
"C" clamps
Bubble level

Test Conditions: Lab environment: 75 ±5°F

Test Procedure:

This was a four-part test using three 1U76034-01 bolts:

Part 1: Ultrasonic elongation in tensile machine

Part 2: Ultrasonic elongation in load collar

Part 3: Mechanical elongation in tensile machine

Part 4: Mechanical elongation in load collar

Ultrasonics:

A 0.335 stress factor was used for all measurements. Procedures per RSRM-BLT-100C for bolt gage setup and use were followed.

Tensile Machine:

A bolt was installed finger-tight in the tensile machine fixturing. The transducer was then placed on the bolt and weighted uniformly so that the transducer did not move. An initial length was taken and the bolts then loaded to the following load levels: 40,000, 60,000, 70,000, 80,000, 90,000, and 100,000 lb. The elongation was recorded at each load level. These procedures were repeated for all bolts.

Load Collar:

A bolt was installed finger-tight in the load collar fixturing. An initial length measurement was taken on the bolt. The transducer was removed and the bolt loaded to each of the following load levels: 40,000, 60,000, 70,000, 80,000, 90,000, 100,000, 120,000, and 140,000 lb. These procedures were repeated for all bolts.

Mechanical Length:

Urethane glue was used to attach a 0.5-in-dia steel ball to each of the three bolts. The steel ball in the head depression was shimmed so that its height was just above the level of the head.

Tensile Machine:

A bolt was installed finger-tight in the tensile machine fixturing. The "C" fixture was mounted in the photo stand at the end of the crossbeam, assuring that the fixture was level. A zero reference measurement was taken with the dial indicator mounted in the "C" fixture. The measurement was verified to be the highest repeatable (minimum 3 repeats). The bolts were then loaded to the following levels, taking elongation measurements each time: 40,000, 60,000, 70,000, 80,000, 90,000, and 100,000 lb.

Load Collar:

A bolt was installed finger-tight in the load collar fixturing. The "C" fixture was held manually and a zero reference measurement was taken. The measurement was verified to be the highest repeatable (minimum 3 repeats). The bolt was then loaded to the following load levels: 40,000, 60,000, 70,000, 80,000, 90,000, 100,000, 120,000, and 140,000 lb.

Tables 5.2.2-1 through 5.2.2-5 and Figures 5.2.2-1 through 5.2.2-3 show mechanical length measurements at known tensile loads.

a. Introduction and Summary. Data from testing done in January 1988 showed that there is a difference between the Boltmaster® ultrasonic readings when used with the load collar versus those with the tensile machine. Analysis of the procedures involved in the calibration showed that the method of calibrating the Boltmaster® assumed two things: 1) the speed of an ultrasonic signal is not affected by torsion, and 2) the load collar load reading is not affected by torsion.

Since there was a difference in the two processes, one of these two assumptions could not be true. Testing was conducted between 29 Mar and 6 Apr 1988 to build a traceable data path for calibration of the Boltmaster® ultrasonic bolt gage and prove which of the above assumptions was not true.

To conclusively determine this, a constant datum was required that linked torsion to tension. A baseline of elongation was used for this test. A single method of measuring the stretch in the bolt was used in both instances. The theory behind the test was that (Hooke's Law being constant in torsion/tension and pure tension) if the bolt stretched the same in the load collar as in the tensile machine, then the ultrasonic

Table 5.2.2-1. Ultrasonic Length Measurements on Tensile Machine

Stress factor: 0.335 in.*

Load (lb)	Elongation (in.) Bolt 1	Bolt 50	Bolt 51
40,000	0.00263	0.00291	0.00286
60,000	0.00404	0.00422	0.00422
70,000	0.00472	0.00495	0.00503
80,000	0.00542	0.00568	0.00572
90,000	0.00611	0.00641	0.00641
100,000	0.00681	0.00713	0.00708

18-point linear correlation: 0.99578 in.
Slope (load factor): 1.4086×10^7 lb/in.
Y-intercept: 1,065 lb
Elongation at 140,000 lb: 0.00986 in.

*Data were adjusted for an average stress factor of 0.335 inch. The actual stress factors were: Bolt 1 - 0.334 in., Bolt 50 - 0.329 in., and Bolt 51 - 0.332 in.

Table 5.2.2-2. Mechanical Length Measurements on Tensile Machine

Load (lb)	Elongation (in.) Bolt 1	Bolt 50	Bolt 51
40,000	0.0031	0.0023	0.0028
60,000	0.0043	0.0045	0.0045
70,000	0.0054	0.0050	0.0048
80,000	0.0058	0.0056	--
90,000	0.0062	0.0062	--
100,000	0.0066	0.0069	--

Mechanical length, 15-point correlation: 0.98205 in.
Slope: 1.4417×10^7 lb/in.
Y-intercept: -1,122 lb
Elongation at 140,000 lb load: 0.00979 in.

Table 5.2.2-3. Mechanical Length Measurements in Load Collar

Bolt No.	Load (lb)	Elongation (in.)
1	41,441	0.0033
	59,152	0.0039
	69,974	0.0047
	80,010	0.0052
	89,062	0.0057
	102,246	0.0065
	125,466	0.0076
50	41,638	0.0028
	61,907	0.0034
	74,107	0.0041
	81,781	0.0052
	100,672	0.0061
	118,185	0.0071
	138,257	0.0085
51	39,474	0.0029
	60,923	0.0045
	72,336	0.0046
	84,733	0.0055
	93,195	0.0063
	101,263	0.0068
	118,579	0.0076
	137,273	0.0082

Mechanical length, 22-point compound linear correlation:	0.9828 in.
Slope:	1.7295×10^7 lb/in.
Y-intercept	-9,729 lb
Elongation at 140,000 lb:	0.00866 in.

Table 5.2.2-4. Ultrasonic Length Measurements in Load Collar

Bolt No.	Load (lb)	Elongation (in.)
1	44,099	0.0021
	64,071	0.0034
	74,303	0.0039
	80,797	0.0043
	88,865	0.0048
	102,443	0.0055
	137,076	0.0077
50	42,819	0.0029
	61,316	0.0041
	72,336	0.0048
	80,207	0.0052
	92,604	0.0059
	103,230	0.0066
	137,470	0.0087
51	40,261	0.0025
	62,890	0.0039
	72,336	0.0045
	83,945	0.0052
	93,588	0.0057
	101,459	0.0062
	139,438	0.0086

Ultrasonic length, 21-point linear correlation:	0.9738 in.
Slope:	1.56838×10^7 lb/in.
Y-intercept	5,011 lb
Elongation at 140,000 lb:	0.00861 in.

Table 5.2.2-5. Adjusted Load Ultrasonic Length Measurements in Load Collar*

Bolt No.	Load (lb)	Elongation (in.)
1	38,366	0.0021
	55,742	0.0034
	64,644	0.0039
	70,293	0.0043
	77,312	0.0048
	891,253	0.0055
	119,256	0.0077
50	37,252	0.0029
	53,345	0.0041
	62,932	0.0048
	69,780	0.0052
	80,565	0.0059
	89,810	0.0066
	119,599	0.0087
51	35,027	0.0025
	54,714	0.0039
	62,932	0.0045
	73,032	0.0052
	81,374	0.0057
	88,269	0.0062
	121,311	0.0086

Ultrasonic length, 21-point linear correlation:	0.9738 in.
Slope:	1.3644×10^7 lb/in.
Y-intercept	4,359 lb
Elongation at 140,000 lb:	0.00994 in.

*Load = 87 percent of Table 5.2.2-4

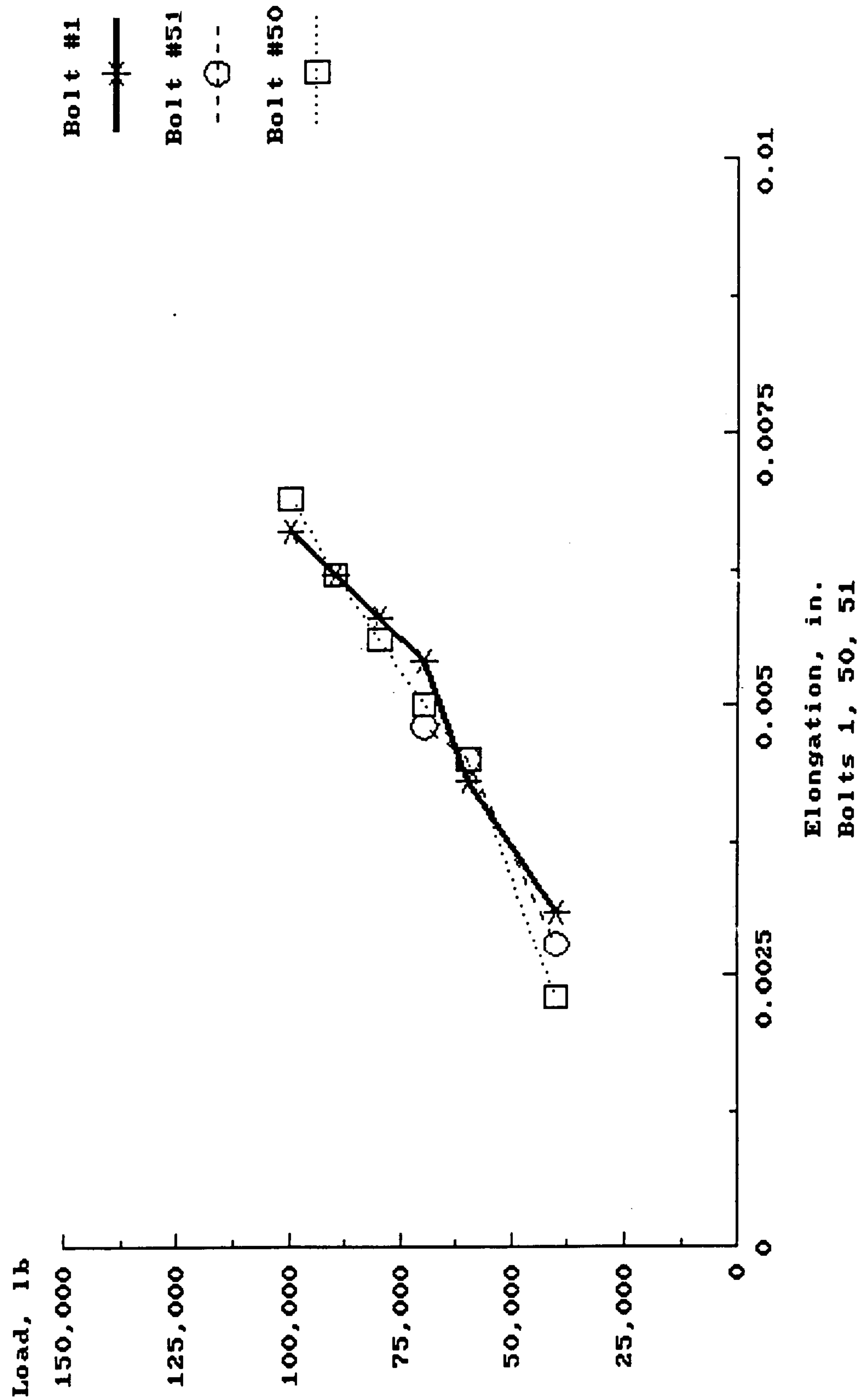


Figure 5.2.2-1. Dial Indicator Elongation Measurements (Tensile Machine)

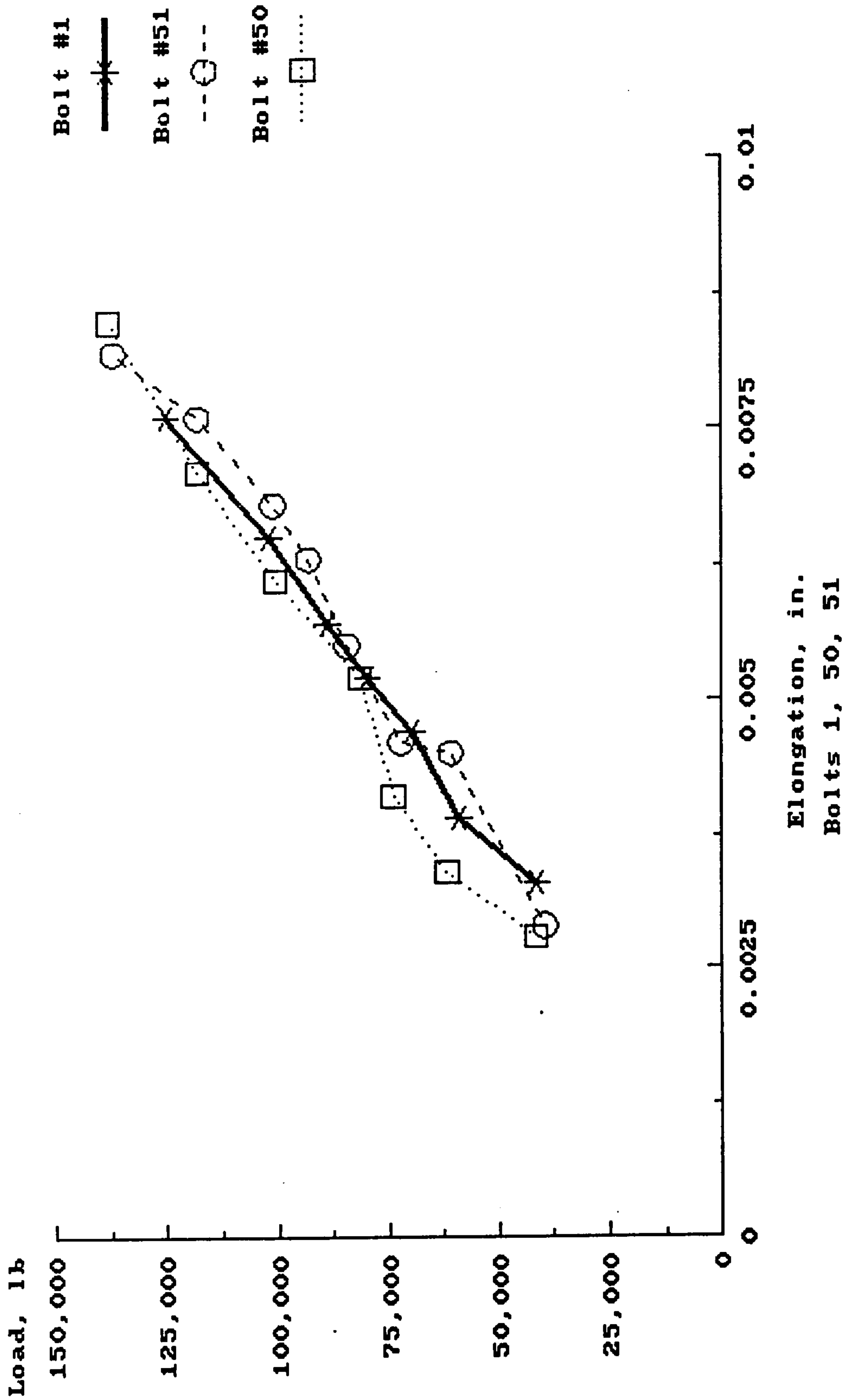


Figure 5.2.2-2. Dial Indicator Length Measurements (Load Collar)

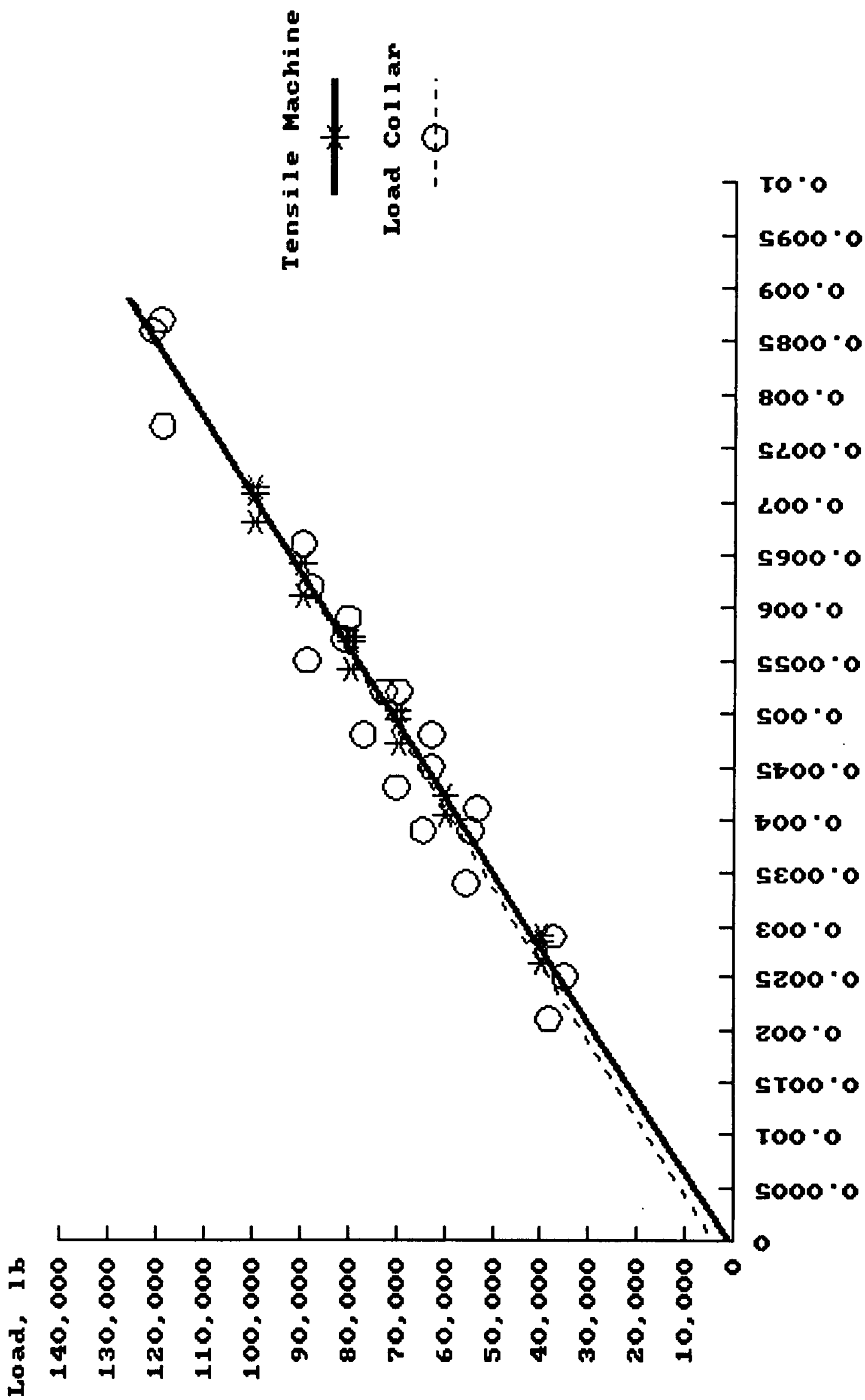


Figure 5.2.2-3. Adjusted Ultrasonic Readings, Tensile Machine Versus Load Collar (Axial Bolts)

signal speed must be affected by torsion, and therefore be the cause of the error. If the elongation of the bolt was different in the two setups at the same load, then the load collar must be affected by torsion, which would make it the cause of the error.

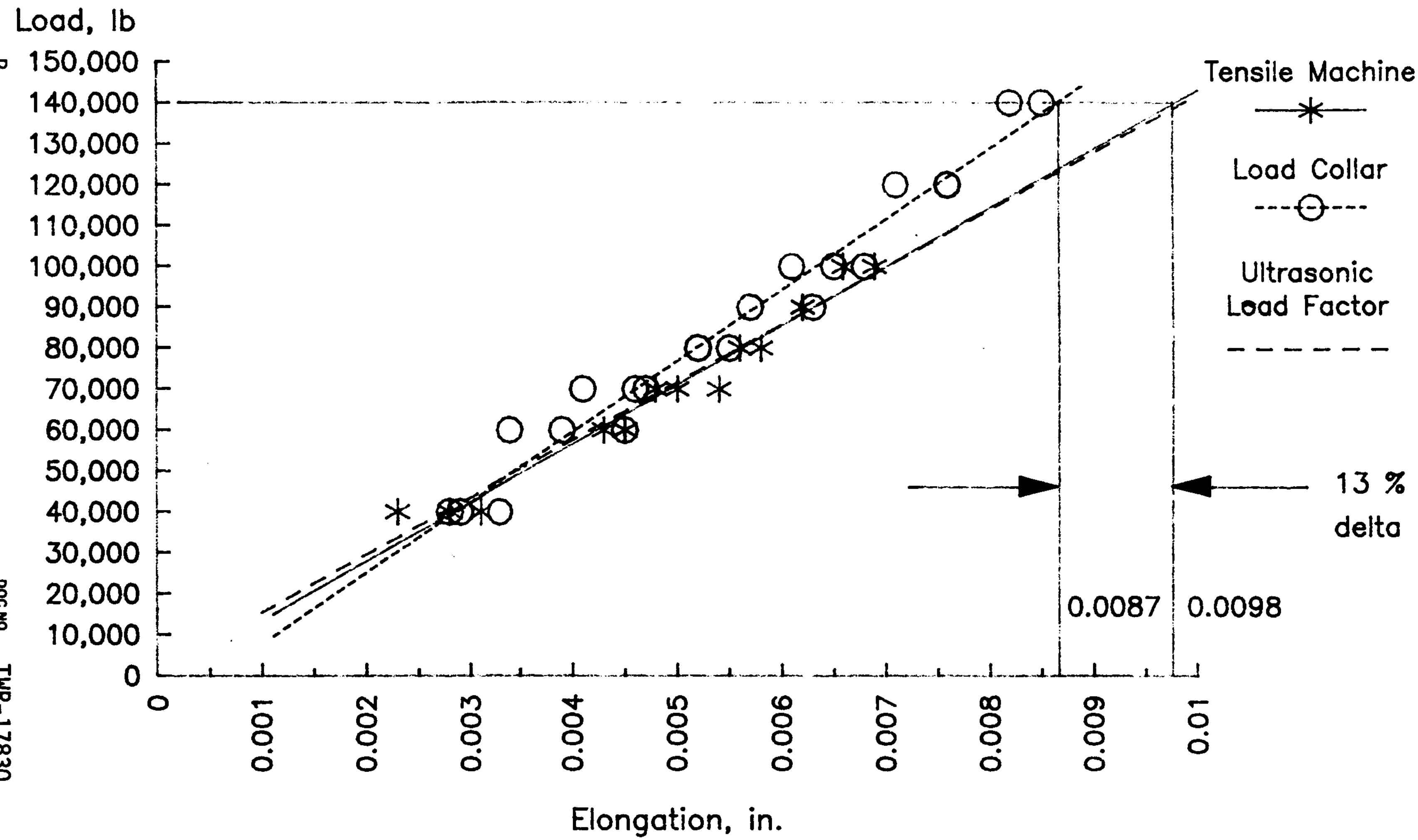
Testing was done on three bolts that were set up for accurate length measurements. The bolts were loaded in the load collar, load readings were taken, and elongation readings were taken. The same test was then run on the tensile machine.

Test data showed that there was a 13-percent variation in actual length between the tensile machine and the load collar (Figure 5.2.2-4). Therefore, according to the test theory, the load collar was incorrect, reading a value 13 percent greater than the actual load on the bolt.

b. Conclusions. The data show that the load collar requires an elongation 13-percent less than the tensile machine. If the bolt is stretching less, then the load must truly be less. Therefore, the load collar is affected by the variation between its calibration and its use. The major difference between calibration and use is that the load collar is calibrated in pure compression, and then used in compression/torsion. This difference probably accounts for the majority of the error. Other possible factors are the bending of the bolt while it is being torqued and nonparallelism between the underside of the bolt head and the load collar. Test data from a comparison between the load collar and the tensile machine, using Strainsert bolts as a constant datum, showed the same 13-percent error. This supports the conclusion that the error is due entirely to the load collar.

By adjusting the load collar data 13 percent to give actual load, and comparing the ultrasonic elongation data from the tensile machine and the load collar, the observation can be made that the ultrasonic signal speed does not change between pure tensile and tensile/torsional loading.

c. Recommendations. Since the data show that the tensile machine is the most accurate way to calibrate to load, all future calibration work should be done in it.



All Measurements taken with a Dial Indicator mounted in a "C" fixture.

Figure 5.2.2-4. Elongation Comparison, Load Collar Versus Tensile Machine

Further work should be done to determine the effect of torsion on the load collar. The testing done here has only shown that the load collar is affected by the difference between the way the load collar is calibrated and the way it is used. Torsion is the most likely suspect, but there are other possible places for error.

d. Discussion and Results. To accurately measure bolt preload using the Boltmaster® ultrasonic bolt gage, it is necessary to have traceable data backing up all calibrations. Defining and building this traceable data path is the problem being investigated.

The intent of this test is to quantify and assign the error found between tensile loading bolts in a tensile machine and tensile/torsion loading bolts in a load collar.

This test is specifically designed to determine the requirements to accurately calibrate the Boltmaster® ultrasonic bolt gage for SRM nozzle axial bolts. Based on the results from this testing, further testing will be performed on the SRM nozzle radial bolts.

The proposed test plan calls for the use of a baseline of mechanical change in length for determination of all other values. The reason for this is that according to Hooke's Law,

$$d = \frac{PL}{AE}$$

A, E, and L are constants, and bolt load (P) is directly related to bolt stretch (d). Therefore, testing based upon stretch is equivalent to testing based upon load.

Our ability to measure accurate length measurements in the tensile machine and in the load collar will allow us to quantify the errors of these two methods. Generally, the testing should be performed as follows:

1. Take mechanical length measurements at various load levels in the Baldwin tensile machine.
2. Take ultrasonic length measurements at the same load levels in the Baldwin tensile machine.

3. Take mechanical length measurements at the various load levels in the load collar.

4. Take ultrasonic length measurements at the same levels in the load collar.

5. Use the length measurements to determine errors for the load collar versus Baldwin tensile machine for load and ultrasonic length data.

5.2.3 Strainsert and Ultrasonic Bolt Load Reading Comparison

A listing of the test equipment, lot conditions, and testing procedures is as follows:

Test Hardware:

Baldwin tensile machine
0.875-in.-dia load collar (Appendix A)
1.375-in.-dia load collar (Appendix A)
Voltage output monitor
PDX 934-01 bolt gage
PDX 769 axial bolt transducer
PDX 770 radial bolt transducer
Strainsert monitor
Ten 1U75167-02 bolts
Ten 1U76034-02 bolts
Ten 1U75311-03 bolts
Ten 1U75311-05 bolts

Test Fixtures:

Tensile machine adapter tooling for both radial and axial bolts (Appendix A)

Test Conditions: Lab environment: 75 ±5°F

Test Procedure:

This is an eight-part test matrix. Each bolt type was tested in each loading method.

Bolt Type	Loading Method
1U75167-02	Load collar
1U76034-02	Tensile machine
1U75311-03	Tensile machine
1U75311-05	Tensile machine

RSRM-BLT-100C for bolt gage setup and signal setup was followed. The Strainsert monitor was calibrated for the Strainsert bolts to be tested. The load collars were calibrated for their respective bolt types.

The bolts were loaded as follows, taking load and elongation measurements from each applicable machine, as well as ultrasonic information on the non-Strainsert bolts:

Load Collar (kips)		Tensile Machine (kips)	
Radial Bolts	Axial Bolts	Radial Bolts	Axial Bolts
20	20	10	20
30	40	20	40
40	60	30	60
45	80	35	70
50	100	40	80
55	120	45	90
	140	50	100

a. Introduction and Summary. Testing was done to compare the Strainsert bolts to the ultrasonic bolts in both the tensile machine and the load collar. The purpose of this test was to determine the best method of ultrasonically calibrating the bolts so that they were equivalent to the Strainsert bolts when torqued into a nozzle joint (Tables 5.2.3-1 through 5.2.3-8). A summary of the data follows:

Axial Bolt Analysis of Variations

Ultrasonic bolt in tensile machine

Range at 120,000 lb: -10 to -2.2 percent
Average: -6 percent

Table 5.2.3-1. Radial Bolts, Ultrasonics in Tensile Machine

Bolt No.	Tensile Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
8-5	10,000	11,330	0.0013
	20,000	22,820	0.0026
	30,000	34,311	0.0039
	35,000	41,382	0.0047
	40,000	47,570	0.0054
	45,000	52,873	0.0060
	50,000	59,944	0.0068
3	10,000	11,330	0.0013
	20,000	22,820	0.0026
	30,000	35,195	0.0040
	35,000	41,382	0.0046
	40,000	46,686	0.0053
	45,000	52,873	0.0060
	50,000	59,060	0.0067
6	10,000	10,446	0.0012
	20,000	21,937	0.0025
	30,000	33,427	0.0038
	35,000	39,615	0.0045
	40,000	45,802	0.0051
	45,000	51,105	0.0058
	50,000	57,293	0.0065
8	10,000	11,330	0.0013
	20,000	23,704	0.0027
	30,000	35,194	0.0040
	35,000	41,382	0.0047
	40,000	47,570	0.0054
	45,000	53,757	0.0061
	50,000	59,944	0.0068
18	10,000	11,330	0.0013
	20,000	22,820	0.0026
	30,000	33,427	0.0038
	35,000	39,615	0.0045
	40,000	44,918	0.0051
	45,000	54,105	0.0058
	50,000	56,409	0.0064

Table 5.2.3-1. Radial Bolts, Ultrasonics in Tensile Machine (Cont)

Bolt No.	Tensile Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
30	10,000	10,446	0.0012
	20,000	21,937	0.0025
	30,000	33,427	0.0038
	35,000	38,731	0.0044
	40,000	44,034	0.0050
	45,000	49,337	0.0056
	50,000	55,525	0.0063
24	10,000	11,330	0.0013
	20,000	21,937	0.0025
	30,000	33,427	0.0038
	35,000	38,731	0.0044
	40,000	44,034	0.0050
	45,000	49,337	0.0056
	50,000	55,525	0.0063
23	10,000	11,330	0.0013
	20,000	21,937	0.0026
	30,000	33,437	0.0038
	35,000	38,731	0.0044
	40,000	44,034	0.0050
	45,000	49,337	0.0056
	50,000	55,525	0.0063
29	10,000	11,330	0.0012
	20,000	21,937	0.0025
	30,000	32,543	0.0037
	35,000	38,731	0.0044
	40,000	44,034	0.0050
	45,000	48,454	0.0055
	50,000	54,641	0.0062
21	10,000	11,330	0.0013
	20,000	21,937	0.0025
	30,000	32,543	0.0037
	35,000	38,731	0.0044
	40,000	44,034	0.0050
	45,000	49,337	0.0056
	50,000	54,641	0.0062

Table 5.2.3-2. Radial Bolts, Strainserts in Tensile Machine

Bolt No.	Tensile Load (lb)	Strainsert Reading (kips)
88	0	0.80
	10,000	9.88
	20,000	20.59
	30,000	30.60
	35,000	35.54
	40,000	40.60
	45,000	45.60
	50,000	50.60
74	0	1.00
	10,000	10.43
	20,000	20.55
	30,000	30.45
	35,000	35.35
	40,000	40.35
	45,000	45.29
	50,000	50.25
93	0	1.01
	10,000	10.78
	20,000	20.53
	30,000	30.16
	35,000	35.00
	40,000	39.82
	45,000	44.66
	50,000	49.49
67	0	1.01
	10,000	11.03
	20,000	20.73
	30,000	30.46
	35,000	35.23
	40,000	40.12
	45,000	44.98
	50,000	49.84
73	0	0.57
	10,000	10.29
	20,000	20.14
	30,000	30.01
	35,000	34.93
	40,000	39.83
	45,000	44.69
	50,000	49.65

Table 5.2.3-2. Radial Bolts, Strainserts in Tensile Machine (Cont)

Bolt No.	Tensile Load (lb)	Strainsert Reading (kips)
68	0	0.83
	10,000	10.60
	20,000	20.38
	30,000	30.22
	35,000	35.15
	40,000	40.06
	45,000	44.96
	50,000	49.85
70	0	1.05
	10,000	9.66
	20,000	19.98
	30,000	29.86
	35,000	34.79
	40,000	39.71
	45,000	44.60
	50,000	49.56
66	0	0.88
	10,000	10.66
	20,000	20.68
	30,000	30.72
	35,000	35.61
	40,000	40.65
	45,000	45.59
	50,000	50.58
89	0	1.02
	10,000	11.09
	20,000	21.03
	30,000	30.87
	35,000	35.82
	40,000	40.70
	45,000	45.62
	50,000	50.37
85	0	0.34
	10,000	9.09
	20,000	19.24
	30,000	29.54
	35,000	34.65
	40,000	39.76
	45,000	45.04
	50,000	50.09

Table 5.2.3-3. Axial Bolts, Strainserts in Tensile Machine

Bolt No.	Tensile Load (kips)	Strainsert Reading (kips)
172	0	-1.05
	20	18.35
	40	37.93
	60	57.90
	70	67.84
	80	77.80
	90	87.86
	100	97.94
192	0	-1.95
	20	17.15
	40	37.35
	60	57.56
	70	67.70
	80	77.85
	90	88.09
	100	98.42
200	0	-0.74
	20	18.69
	40	38.60
	60	58.92
	70	69.09
	80	79.34
	90	89.60
	100	99.89
195	0	-2.21
	20	17.26
	40	36.97
	60	56.86
	70	67.84
	80	77.80
	90	87.86
	100	97.94
174	0	-1.35
	20	17.97
	40	37.54
	60	57.25
	70	67.08
	80	76.92
	90	86.87
	100	96.93

Table 5.2.3-3. Axial Bolts, Strainserts in Tensile Machine (Cont)

Bolt No.	Tensile Load (kips)	Strainsert Reading (kips)
149	0	-1.35
	20	18.24
	40	38.12
	60	58.02
	70	67.98
	80	78.14
	90	88.21
	100	98.44
158	0	-0.88
	20	19.50
	40	39.54
	60	59.73
	70	69.96
	80	80.20
	90	90.40
	100	100.62
147	0	-1.34
	20	18.02
	40	37.55
	60	57.18
	70	67.12
	80	77.17
	90	87.20
	100	97.44
159	0	-1.40
	20	18.28
	40	38.34
	60	58.37
	70	68.51
	80	78.64
	90	89.19
	100	99.96
154	0	-2.04
	20	17.09
	40	37.62
	60	57.60
	70	62.73
	80	77.92
	90	88.07
	100	98.23

Table 5.2.3-4. Axial Bolts, Ultrasonic in Tensile Machine

Bolt No.	Tensile Load (kips)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
99	20	18,480	0.0013
	40	41,136	0.0028
	60	62,282	0.0042
	70	74,365	0.0050
	80	84,938	0.0057
	90	95,511	0.0064
	100	105,083	0.0071
	120	127,229	0.0085
105	20	21,501	0.0015
	40	42,647	0.0029
	60	66,813	0.0045
	70	77,386	0.0052
	80	87,959	0.0059
	90	92,490	0.0062
	100	103,063	0.0069
	120	127,229	0.0085
97	20	19,991	0.0014
	40	39,626	0.0027
	60	60,771	0.0041
	70	69,834	0.0047
	80	80,407	0.0054
	90	90,979	0.0061
	100	101,552	0.0068
	120	122,698	0.0082
85	20	19,991	0.0014
	40	41,136	0.0028
	60	63,742	0.0043
	70	74,365	0.0050
	80	84,938	0.0057
	90	95,511	0.0064
	100	102,594	0.0072
	120	128,739	0.0086
107	20	19,991	0.0014
	40	39,626	0.0027
	60	60,771	0.0041
	70	71,344	0.0048
	80	81,917	0.0055
	90	92,490	0.0062
	100	103,063	0.0069
	120	125,719	0.0084

Table 5.2.3-4. Axial Bolts, Ultrasonic in Tensile Machine (Cont)

Bolt No.	Tensile Load (kips)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
93	20	19,991	0.0014
	40	41,136	0.0028
	60	63,792	0.0043
	70	74,365	0.0050
	80	84,938	0.0057
	90	95,511	0.0064
	100	106,083	0.0071
	120	128,739	0.0086
94	20	19,991	0.0014
	40	39,626	0.0027
	60	62,282	0.0042
	70	72,855	0.0049
	80	83,427	0.0056
	90	94,000	0.0063
	100	104,573	0.0070
	120	125,719	0.0084
98	20	21,501	0.0015
	40	42,647	0.0029
	60	63,792	0.0044
	70	75,875	0.0051
	80	86,448	0.0058
	90	97,021	0.0065
	100	109,104	0.0073
	120	131,760	0.0088
96	20	19,991	0.0014
	40	42,647	0.0029
	60	63,792	0.0043
	70	75,875	0.0051
	80	84,938	0.0057
	90	95,511	0.0064
	100	107,594	0.0072
	120	128,739	0.0086
100	20	19,991	0.0014
	40	41,136	0.0028
	60	60,771	0.0041
	70	71,344	0.0048
	80	81,917	0.0055
	90	92,490	0.0062
	100	103,063	0.0069
	120	124,208	0.0083

Table 5.2.3-5. Radial Bolts, Strainserts in Load Collar Load

Bolt No.	Collar Load (lb)	Strainsert Reading (kips)
88	0	+0.88
	20,891	20.56
	33,251	30.68
	37,545	33.00
	47,181	41.12
	52,627	45.48
	60,378	51.56
66	0	+0.71
	21,834	20.58
	34,403	30.88
	39,954	35.31
	46,343	40.39
	53,674	46.27
	59,121	50.76
85	0	+0.39
	21,310	19.11
	34,088	29.61
	40,477	34.79
	46,522	39.72
	53,076	45.08
	60,378	51.04
68	0	0.93
	21,206	20.38
	35,031	31.37
	41,525	36.50
	46,343	40.30
	52,313	44.88
	60,482	51.27
89	0	1.02
	23,091	21.45
	34,193	30.60
	40,373	35.67
	46,238	40.37
	53,674	46.28
	59,330	50.82

Table 5.2.3-5. Radial Bolts, Strainserts in Load Collar Load (Cont)

Bolt No.	Collar Load (lb)	Strainsert Reading (kips)
70	0	1.16
	22,463	20.67
	32,936	29.24
	40,136	35.02
	45,505	39.21
	53,989	46.08
	58,388	49.58
73	0	0.69
	20,996	20.26
	33,041	29.87
	39,221	34.68
	45,610	39.74
	51,999	44.97
	58,388	49.80
74	0	1.33
	21,415	20.26
	32,936	29.75
	39,116	34.72
	44,772	39.47
	50,532	44.16
	56,607	49.22
67	0	1.19
	22,358	20.87
	34,612	30.92
	40,582	35.92
	45,714	40.08
	51,370	44.61
	57,969	49.94
93	0	1.45
	21,625	20.70
	33,251	30.00
	39,535	35.02
	46,029	40.12
	51,265	44.33
	57,026	48.90

Table 5.2.3-6. Radial Bolts, Ultrasonics in Load Collar Load

Bolt No.	Collar Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
23	19,739	--	--
	34,403	29,892	0.0034
	36,288	31,659	0.0036
	40,792	34,311	0.0036
	44,876	37,847	0.0043
	49,904	42,266	0.0048
29	20,682	18,401	0.0021
	30,004	26,356	0.0030
	35,555	29,008	0.0033
	40,163	34,311	0.0039
	44,981	36,079	0.0041
	49,904	42,266	0.0048
8	21,101	21,937	0.0025
	30,003	29,892	0.0034
	35,450	34,311	0.0039
	39,954	40,498	0.0046
	44,876	43,150	0.0049
	49,904	48,454	0.0055
3	21,520	22,820	0.0026
	30,946	33,427	0.0038
	36,602	36,963	0.0042
	40,687	38,731	0.0044
	44,667	44,034	0.0050
	52,103	51,989	0.0059
30	20,682	17,517	0.0020
	30,108	26,356	0.0030
	37,440	29,008	0.0034
	41,525	35,195	0.0040
	44,981	37,847	0.0043
	50,637	41,382	0.0047
21	20,996	20,169	0.0020
	29,899	25,472	0.0029
	36,916	31,659	0.0036
	40,896	36,079	0.0041
	45,924	40,498	0.0046
	50,532	42,266	0.0048

Table 5.2.3-6. Radial Bolts, Ultrasonics in Load Collar Load (Cont)

Bolt No.	Collar Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
6	20,158	18,401	0.0021
	30,842	27,240	0.0031
	36,078	29,892	0.0034
	39,954	34,311	0.0039
	44,981	38,731	0.0044
	53,255	44,034	0.0050
24	20,054	18,401	0.0021
	30,632	26,356	0.0030
	36,288	30,776	0.0035
	40,896	35,195	0.0040
	45,819	38,731	0.0044
	49,590	41,382	0.0047
8.5	19,949	21,053	0.0024
	30,213	31,659	0.0036
	36,078	35,195	0.0040
	42,048	40,498	0.0046
	46,552	44,918	0.0051
	52,941	46,686	0.0053
18	19,949	17,517	0.0020
	30,003	25,472	0.0029
	36,497	31,659	0.0036
	40,163	34,311	0.0039
	46,552	38,731	0.0044
	50,427	42,266	0.0048

Table 5.2.3-7. Axial Bolts, Strainserts in Load Collar Load

Bolt No.	Collar Load (lb)	Strainsert Reading (kips)
200	0	-0.71
	21,317	22.30
	40,043	39.45
	62,156	59.30
	79,288	75.10
	99,409	93.00
	120,326	112.00
	139,849	139.71
192	0	-1.70
	19,724	18.91
	39,645	37.10
	59,566	55.00
	84,070	77.20
	99,210	90.90
	119,928	110.40
	139,650	131.40
195	0	-2.10
	20,321	15.83
	39,645	33.80
	61,957	54.80
	80,285	72.20
	100,006	91.10
	119,131	109.80
	139,053	131.50
147	0	-1.20
	20,520	17.30
	39,645	34.90
	60,363	53.30
	80,085	71.20
	104,987	94.10
	120,725	109.00
	140,845	129.90
159	0	-1.26
	20,520	19.50
	39,844	38.00
	59,765	56.70
	80,285	76.00
	100,803	113.00
	119,530	133.30
	140,646	134.26

Table 5.2.3-7. Axial Bolts, Strainserts in Load Collar Load (Cont)

Bolt No.	Collar Load (lb)	Strainsert Reading (kips)
164	0	-2.10
	20,321	20.12
	47,215	44.90
	59,765	56.50
	79,687	74.54
	100,006	93.16
	120,127	111.76
	139,650	130.15
172	0	-0.70
	19,723	18.34
	41,430	38.94
	59,964	56.15
	79,687	74.30
	49,210	92.45
	119,530	111.30
	140,247	131.55
158	0	-0.81
	20,520	19.40
	40,442	38.65
	60,762	57.35
	81,081	76.80
	100,206	93.11
	120,127	111.40
	139,849	130.45
174	0	-1.10
	30,880	30.60
	39,844	38.90
	60,164	57.70
	83,273	79.00
	101,003	95.34
	120,326	113.34
	140,049	133.30
149	0	-1.05
	20,719	16.65
	40,840	35.90
	60,363	53.90
	81,081	73.02
	100,206	90.70
	120,725	110.30
	139,849	128.70

Table 5.2.3-8. Axial Bolts, Ultrasonics in Load Collar Load

Bolt No.	Collar Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
94	20,720	23,011	--
	39,645	39,626	--
	62,156	57,751	--
	82,277	72,855	--
	101,401	90,979	--
	119,928	121,187	0.0081
	139,849	130,250	0.0087
95	20,521	23,011	0.0016
	39,645	42,647	0.0029
	59,766	62,282	0.0042
	80,882	80,407	0.0054
	100,405	98,531	0.0066
	120,525	119,167	0.0079
	140,049	136,291	0.0091
76	20,321	23,011	0.0016
	40,442	41,136	0.0028
	60,164	57,751	0.0039
	80,085	75,875	0.0051
	100,405	90,979	0.0061
	120,127	108,394	0.0072
	140,447	125,719	0.0084
107	21,118	23,011	0.0016
	40,043	41,136	0.0028
	60,164	59,261	0.0040
	80,484	77,386	0.0052
	101,800	97,021	0.0065
	121,721	113,635	0.0076
	140,049	130,250	0.0087
105	20,321	21,501	0.0015
	29,849	41,136	0.0028
	59,765	59,261	0.0040
	79,886	78,896	0.0053
	100,206	95,511	0.0064
	141,123	116,656	0.0078
	139,849	133,271	0.0089

Table 5.2.3-8. Axial Bolts, Ultrasonics in Load Collar Load (Cont)

Bolt No.	Collar Load (lb)	Ultrasonic Load (lb)	Ultrasonic Elongation (in.)
98	20,321	26,032	0.0018
	40,043	38,115	0.0026
	59,965	59,261	0.0040
	81,878	78,896	0.0053
	100,006	95,511	0.0064
	120,127	113,635	0.0076
	140,248	131,760	0.0088
100	19,923	23,011	0.0017
	40,043	41,157	0.0030
	59,965	65,303	0.0044
	79,886	83,427	0.0056
	99,608	94,000	0.0063
	121,322	112,125	0.0075
	140,049	128,739	0.0086
93	20,520	21,501	0.0015
	39,844	39,626	0.0027
	60,164	57,751	0.0039
	80,285	75,875	0.0051
	100,604	94,000	0.0063
	120,725	112,125	0.0075
	140,048	131,760	0.0087
96	20,919	24,522	0.0017
	40,043	45,667	0.0031
	59,965	65,303	0.0044
	78,990	78,896	0.0053
	101,209	100,042	0.0067
	119,928	116,656	0.0078
	142,439	136,291	0.0091

Ultrasonic bolt in load collar

Range at 140,000 lb: 2.7 to 11.7 percent
Average: 6.9 percent

Strainsert bolt in tensile machine

Range at 100,000 lb: -1.5 to 6.4 percent
Average: 0.6 percent

Strainsert bolt in load collar

Range at 140,000 lb: 4.8 to 8.4 percent
Average: 6.5 percent

Total variation between the ultrasonic readings on the tensile machine and on the load collar:

-6 to +6.9 percent: 12.9 percent total variation

Total variation between the Strainsert readings on the tensile machine and on the load collar:

0.6 to 6.45 percent: 5.85 percent total variation

Radial Bolt Analysis of Variation

Ultrasonic calibration values*

Stress Factor: 0.448
Load Factor: 8.839 E6 lb/in.
Y-intercept: -161 lb

All data are at 50,000-lb load.

Ultrasonic bolt in tensile machine

Range: -16.6 to -8.5 percent
Average: -12 percent

Ultrasonic bolt in load collar

Range: 0.2 percent
Average: 15.4 percent

Strainsert bolt in tensile machine

Range: 0.4 to 3.1 percent
Average: 1.68 percent

*These calibration values were generated on a load collar.

Strainsert bolts in load collar

Range: 18.1 to 20.8 percent

Average: 19.2 percent

Total variation between ultrasonics in tensile machine and ultrasonics in load collar:

-12 to 15.4 percent: 27.4 percent total variation

Total variation between Strainserts in tensile machine and Strainserts in load collar:

1.68 to 19.2 percent: 17.52 percent total variation

b. Conclusions. From this data it can be seen that the Strainsert bolts agree very well with the tensile machine. The ultrasonic axial bolts need a slight adjustment to read closer to the tensile machine, while the ultrasonic radial bolts require a somewhat larger adjustment.

There is some discrepancy in the total error that the Strainsert and ultrasonic bolts experience between the tensile machine and the load collar. The Strainserts have a smaller percentage difference. One hypothesis follows:

> The process of torquing a bolt into a load collar causes a higher load reading at any given actual load than if the load collar is loaded in pure compression in a tensile machine. If a Strainsert bolt has the same type of effect, then a Strainsert would show a higher load reading when torqued than when loaded in pure tension. If a Strainsert bolt were torqued into a load collar, then at a given load the Strainsert would read higher, closing in on the load collar reading. This would reduce the amount of error seen between the Strainsert and the load collar.

When the data are interpreted according to the above hypothesis, it is possible that the Strainserts are in error by as much as 6 percent on the axial bolt and 10 percent on the radial bolts. This is an area for further study.

c. Recommendations. Since the Strainsert bolts are calibrated, the tensile machine is calibrated, and they agree, all future calibration work should be done specifically on the tensile machine.

More work could be done to determine the cause of the difference in the amount of error between Strainsert and ultrasonic bolts in the two loading methods, tensile machine and the load collar.

d. Discussion and Results. All data were recorded with a single set of calibration factors:

	Axial Bolts	Radial Bolts
Stress Factor:	0.330	0.448
Load Factor (lb/in.):	1.5104 E7	8.839 E6
Y-intercept (lb):	-1,155	-161

To convert data based on these calibration factors to agree with the tensile machine, the following technique was used:

1. Determine a theoretical stretch for a given load on the fastener: S_t

2. Calculate the stress factor for each of the test bolts at the given load to produce the theoretical stretch:

   (L2 - L1) = measured stretch/old SF

   New SF = S_t/(L2 - L1)

   or

   New SF = S_t(old SF/measured stretch)

3. Average all of the new SFs:

   $$SF = \frac{SUM\ (new\ SF)}{N}$$

4. Recalculate the elongation for each of the data points:

   New elongation = old elongation x (SF)/(old SF)

5. Do a linear regression on all of the data points to produce a slope and a Y-intercept. The slope = LF, and the Y-intercept = Y.

   To calculate Strainsert load from the Strainsert voltage reading: 1) subtract the zero-load Strainsert reading from each loaded Strainsert reading, and 2) multiply each by 1,000.

5.2.4 Nozzle Bolt Calibrations

A listing of the test equipment, lot conditions, and testing procedures is as follows:

Test Hardware:

- Baldwin tensile machine
- 0.875-in. load collar (Appendix A)
- 1.375-in. load collar (Appendix A)
- Voltage output monitor
- 1U75167 bolts (as stated in data)
- 1U76034 bolts (as stated in data)
- PDX 934-01 bolt gage
- PDX 769 axial transducer
- PDX 770 radial transducer

Test Fixture:

- Tensile machine adapter tooling for radial and axial bolts (Appendix A)
- 0.875-in. cross bolt and 1.375-in. axial bolt threaded hole plates (Appendix A)

Test Conditions: Lab environment: 75 ±5°F

Test Procedure: Refer to Section 5.2.4d.

a. Introduction and Summary. Nozzle bolt calibration has gone through a number of iterations. Calibration work began by torquing bolts into a strain-gaged load collar; later it was found that the load collar caused errors in the load readings. A number of tests were performed to correlate the ultrasonics to other forms of load measurement.

Two sets of tests were performed by Morton Thiokol and REI, one for the axial bolts and one for the radial bolts. The charts in Figures 4.1.4-1 and 4.1.4-2 show how the values compare to each other. A raw elongation value is converted to a load reading, and then plotted on its associated curve. Note that the scatter along the Y axis is the significant value.

b. Conclusions. From the charts it can be seen that regardless of the number of different slopes, the output load value for each of the four curves has a fairly tight scatter. This means that the theoretical elongation value chosen for the test can be arbitrary as long as the slope is adjusted to compensate.

c. Recommendations. For the axial bolts, a conservative data point closest to the center of the Y axis scatter band is the Morton Thiokol second calibration. To achieve the smallest error, this "average" point should be chosen as most correct, and the corresponding calibration values should be used for all axial bolt work.

For the radial bolts, the largest and most accurate data base is that performed on the tensile machine at Morton Thiokol.

d. Discussion and Results. The problem under investigation is the determination of nozzle bolt calibration factors. The objective of the investigation is to obtain the most correct calibration factors.

There are two methods of obtaining ultrasonic calibration values. The first method is to use the vendor-supplied programs called BOLT and TENSILE. The BOLT program calculates a theoretical elongation based upon the joint design. The theoretical elongation is then used to adjust the bolt gage so that at the working load, the bolt gage displays the theoretical elongation. This adjustment calculates the SF.

The TENSILE program is then used to create a linear regression of load/elongation points on a number of bolts. From this linear regression, the slope and Y-intercept are taken as the LF and the Y-intercept for the bolt gage.

The second method uses BGPRG, the normal operating program. Data are taken in a tensile machine to obtain actual load at each elongation point. The data are then converted as described in the Strainsert and ultrasonic bolt load reading comparison test report.

The pertinent data from the five tests on the axial bolts are shown in Table 5.2.4-1.

5.2.5 Torque Comparison of Ultrasonic and Strainsert Bolts in NJAD

A listing of the test equipment, lot conditions, and testing procedures is as follows:

Table 5.2.4-1. Nozzle Bolt Calibration Data

Calibration	Location	Date	No. Tested	Stress Factor	Load Factor (lb/in.)	Y-intercept (lb/in.)
Axial Bolts						
Original	Morton Thiokol	14 Oct 1987	6	0.464	1.425 E7	7,750
First	REI	2 Jul 1987	3	0.328	15.5 E6	-316
Second	Morton Thiokol	29 Mar 1988	3	0.335	1.4086 E7	1,065
Second	REI	1 Apr 1988	3	0.330	1.5104 E7	-1,155
Third	Morton Thiokol	19 Apr 1988	10	0.310	1.479 E7	1,281
Radial Bolts						
First	REI	2 Jul 1987	1 (short)	0.448	8.488 E6	0
First	Morton Thiokol	Sep 1987	6	0.448	8.839 E6	-161
Second	Morton Thiokol	Mar 1988	10	0.421	8.126 E6	736

Test Hardware:

NJAD aft dome (Drawing 7U50878)
NJAD fixed housing (Drawing 7450877)
Ten 1U75167-04 bolts
Ten 1U76034-02 bolts
Ten 1U75311-03 bolts
Ten 1U75311-05 bolts
PDX 934-01 bolt gage
PDX 769 axial transducer
PDX 770 radial transducer
Minidas Strainsert monitor
3,000 ft-lb torque wrench
600 ft-lb torque wrench

Test Conditions:

Fluctuating temperature conditions. Changes in temperature were compensated for directly through the bolt gage program software.

Test Procedure:

All bolts were installed finger-tight in the joint. One Strainsert, one ultrasonic bolt, and one nonultrasonic bolt were installed in each of the first 10 sequences per STW7-3437A. RSRM-BLT-100C for bolt gage setup and signal setup was followed. The NJAD aft dome and fixed housing were assembled according to Drawings 7U50878 and 7U50877, respectively. Nonultrasonic bolts were installed in all succeeding sequences.

Initial lengths were taken on all ultrasonic bolts and zero readings were taken on the Strainsert bolts.

Bolts were loaded in sequence per STW7-3437A. Torque required to achieve load was monitored and recorded on the final pass for each ultrasonic and Strainsert bolt.

a. Introduction and Summary. From 5 May through 7 May 1988, a comparison test was done to determine the accuracy of the bolt gage as compared to instrumented bolts. This was done as part of the NJAD-3 Test.

A comparison between the different methods used to monitor loads on the axial bolts resulted in a difference of 0.0373 percent between their torque-to-load ratios. The difference in the ratios measured on the radial bolt was 18.89 percent.

b. Conclusion. The test was not a large enough sample to make conclusive statements, especially about the difference in the torque requirements on the radial bolt (Table 5.2.5-1). However, the data indicate that the axial bolts are being loaded to the same load with both the ultrasonic and the Strainsert bolts (Table 5.2.5-2).

c. Recommendations. Since this testing was a small sample, there are no recommendations for changing calibration or procedure. However, this test does substantiate the quality of the new axial bolt calibration data.

d. Discussion and Results. The problem under investigation is the variation in torque values between ultrasonic versus Strainsert bolts. The objective of the investigation is to determine the variation in torque values between ultrasonic and Strainsert bolts.

The test was run using the following Boltmaster® calibration values:

	Axial Bolts	Radial Bolts
Stress Factor (lb/in.)	0.335	0.421
Load Factor:	1.4086 E7	8.126 E6
Y-intercept (lb):	1,065	736
Temperature Factor:	52	53

A verification test was also done which compared the Minidas Strainsert bolt measurements to the Baldwin tensile machine.

	SN	0k lb	100,000 lb
Axial Bolts	195	-60	100,160
	200	-51	99,646

	SN	0k lb	45,000 lb
Radial Bolts	89	95	45,854
	93	129	45,000

Table 5.2.5-1. Torque Comparison, Radial Bolts

	Radial Strainsert		Radial Ultrasonic	
Sequence	Torque (ft/lb)	Load (lb)	Torque (ft/lb)	Load (lb)
1	400	42,793	450	42,991
2	370	47,506	450	42,179
3	370	42,147	500	44,616
4	400	44,770	(200)	(42,991)
5	420	43,081	450	41,366
6	400	42,603	450	41,366
7	370	43,591	400	46,242
8	400	41,273	500	40,553
9	320	41,273	(550)	(35,678)
10	370	43,211	400	43,317

Note: Numbers in parentheses are considered suspect initial lengths and were not used in any calculations.

Table 5.2.5-2. Torque Comparison, Axial Bolts

	Axial Strainsert		Axial Ultrasonic	
Sequence	Torque (ft/lb)	Load (lb)	Torque (ft/lb)	Load (lb)
1	2,400	133,274	2,100	133,473
2	2,200	134,641	2,100	132,065
3	2,100	138,759	2,100	132,065
4	2,000	134,556	2,400	140,516
5	2,000	128,234	2,100	133,473
6	2,100	133,787	2,400	146,172
7	2,200	129,429	2,000	134,882
8	2,200	131,822	2,500	139,108
9	2,000	134,653	1,900	133,473
10	2,200	131,395	2,200	130,656

The results were:

		Strainsert	Ultrasonic
Axial Bolts			
Avg torque (ft/lb):		2,140	2,180
Avg load (lb):		133,055	135,588
Torque load ratio:		16.084 E-3	16.078 E-3
Percent difference:	0.0366		
Radial Bolts			
Avg torque (ft/lb):		382	450
Avg load (lb):		43,225	42,829
Torque load ratio:		8.8375 E-3	10.507 E-3
Percent difference:	18.89		

5.2.6 Ultrasonic Load Versus Grip Length

A listing of the test equipment, lot conditions, and testing procedures is as follows:

Test Hardware:

Baldwin tensile machine
PDX 934-01 bolt gage
PDX 769 axial transducer
PDX 770 radial transducer
Two 1U76034-02 bolts

Test Fixtures:

Tensile machine adapter tooling for axial bolts (Appendix A)

Test Conditions: Lab environment: 75 ±5°F

Test Procedure:

The bolt gage was set up per RSRM-BTL-100C. A bolt was installed in the adapter tooling, which was set to a grip length of 1.60 inches. An initital length measurement was taken on the bolt. The bolt was then loaded to the following tensile load points: 70, 80, 90, and 100 kips. Ultrasonic load was recorded at each load point.

The load points were then repeated at the following increasing grip lengths: 1.77, 1.93, 2.10, 2.27, 2.43, and 2.60 inches.

The above procedure was repeated for the second bolt.

a. Introduction and Summary. Consultations with representatives from NASA/ Langley brought up the question of whether the thread grip point is a constant with the bolts. One hypothesis was that with a new bolt and new hole the grip point is probably very close to the beginning of the threaded hole, but after the bolt and/or the hole have been used a few times, the upper threads wear and the grip point shifts down.

If this is true, then theoretically the bolt gage will lose much of its accuracy. The bolt gage is calibrated to a specific stretch value for a given load. According to Hooke's Law, stretch is proportional to grip length: with a constant load, the longer the grip length, the more stretch will be seen. If the grip length increases, then the bolt gage will read the calibrated stretch value before the bolt reaches the required load.

To test the actual effect of changing grip lengths, bolts were repeatedly loaded to a constant load with increasing grip lengths, and their ultrasonic elongations were read.

The results of the test showed an error significantly lower than what theory predicted.

b. Conclusions. The data showed that the ultrasonics were not as dependent on grip length to determine elongation as theory predicted. This means that regardless of whether the grip length changes over loading cycles, the accuracy of the bolt gage is not compromised.

c. Recommendations. The bolt gage should continue to be used without any modification or compensation for changes in grip length.

d. Discussion and Results. The problem being investigated is whether there is any change in the accuracy of the bolt gage when the grip length changes. The objective of the investigation is to determine the accuracy of the bolt gage with changing grip lengths.

The testing was performed as follows: three axial bolts, P/N 1U76034-02, were tested in the Baldwin tensile machine. Each bolt was tested at the following grips: 1.60, 1.77, 1.93, 2.10, 2.27, 2.43, and 2.60 inches. Each grip was tested at the following load points: 70, 80, 90, and 100 kips (Tables 5.2.6-1 and 5.2.6-2).

There is sufficient documentation to repeat any test.

Table 5.2.6-1. Grip Length Test for Bolt 116

Grip (in.)	70,000 lb	80,000 lb	90,000 lb	100,000 lb
1.60	72,904	82,764	92,624	102,484
1.77	74,312	84,172	95,441	105,301
1.93	75,721	85,581	96,850	106,710
2.10	74,312	84,172	95,441	105,301
2.27	74,312	84,172	95,441	105,301
2.43	74,312	85,581	96,850	106,710
2.60	74,312	84,172	95,441	105,301
Avg	74,312	84,373	95,441	105,301
Error	+6.16%	+5.47%	+6.04%	+5.30%

Table 5.2.6-2. Grip Length Test for Bolt 112

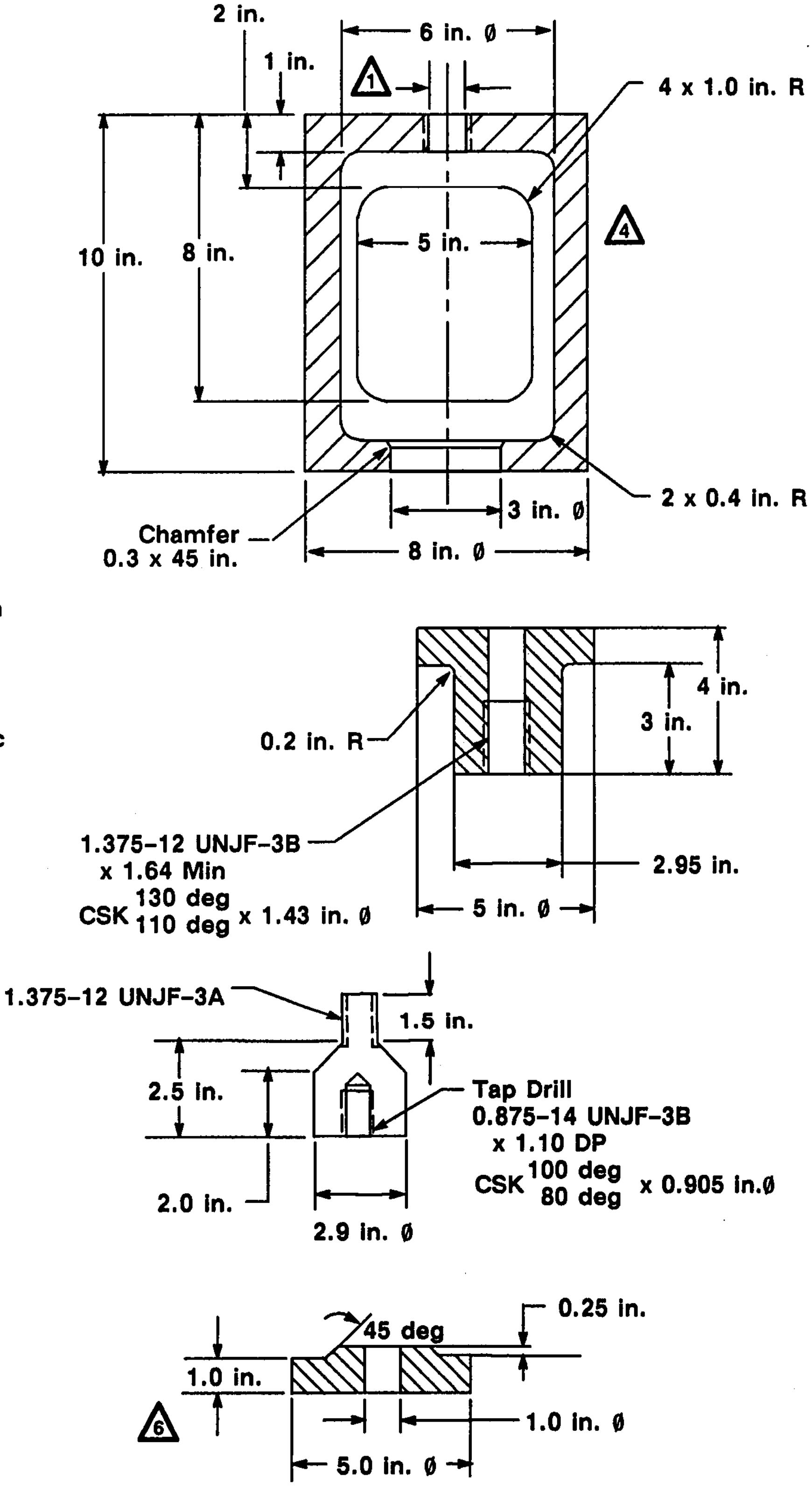
Grip (in.)	70,000 lb	80,000 lb	90,000 lb	100,000 lb
1.60	71,495	79,947	89,807	98,258
1.77	71,495	81,355	91,215	101,076
1.93	71,495	82,764	92,624	102,484
2.10	74,312	84,172	95,441	105,301
2.27	74,312	84,172	95,441	105,301
2.43	72,904	82,764	94,033	103,893
2.60	74,312	84,172	95,441	105,301
Avg	74,312	84,373	95,441	105,301
Error	+6.16%	+5.47%	+6.04%	+5.30%

Appendix A

TEST HARDWARE ILLUSTRATIONS

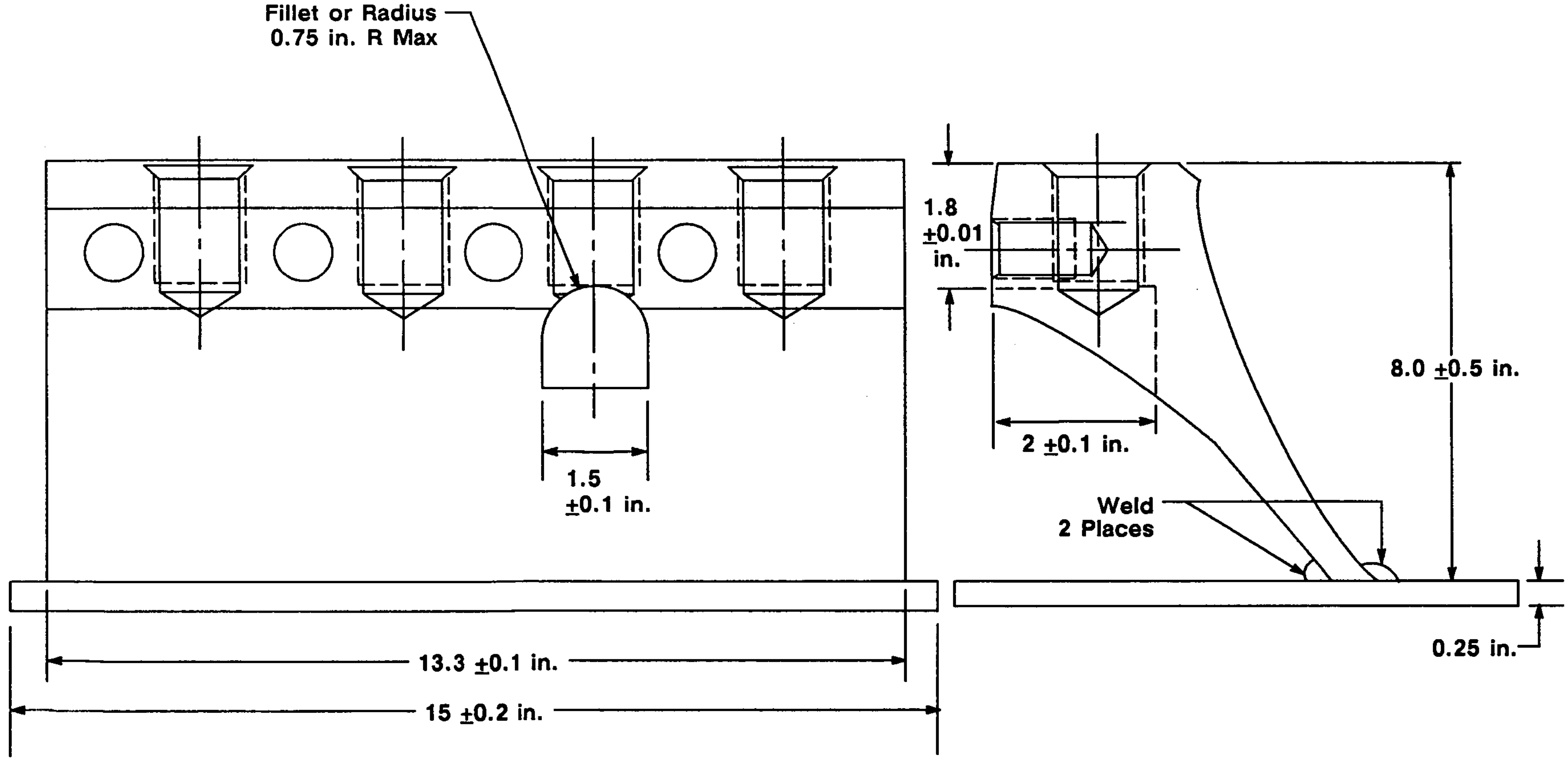
Notes:

1. Threaded hole for tensile machine interface
2. Tolerances ±0.02 in.
3. Material: 4340 Carbon Steel
4. Two required
5. Heat Treat to 36-42Rc
6. Second similar part required with through hole as: 1.438 in. Ø



Drawing SA 10001: Tensile Machine Adapter Tooling

A020974a

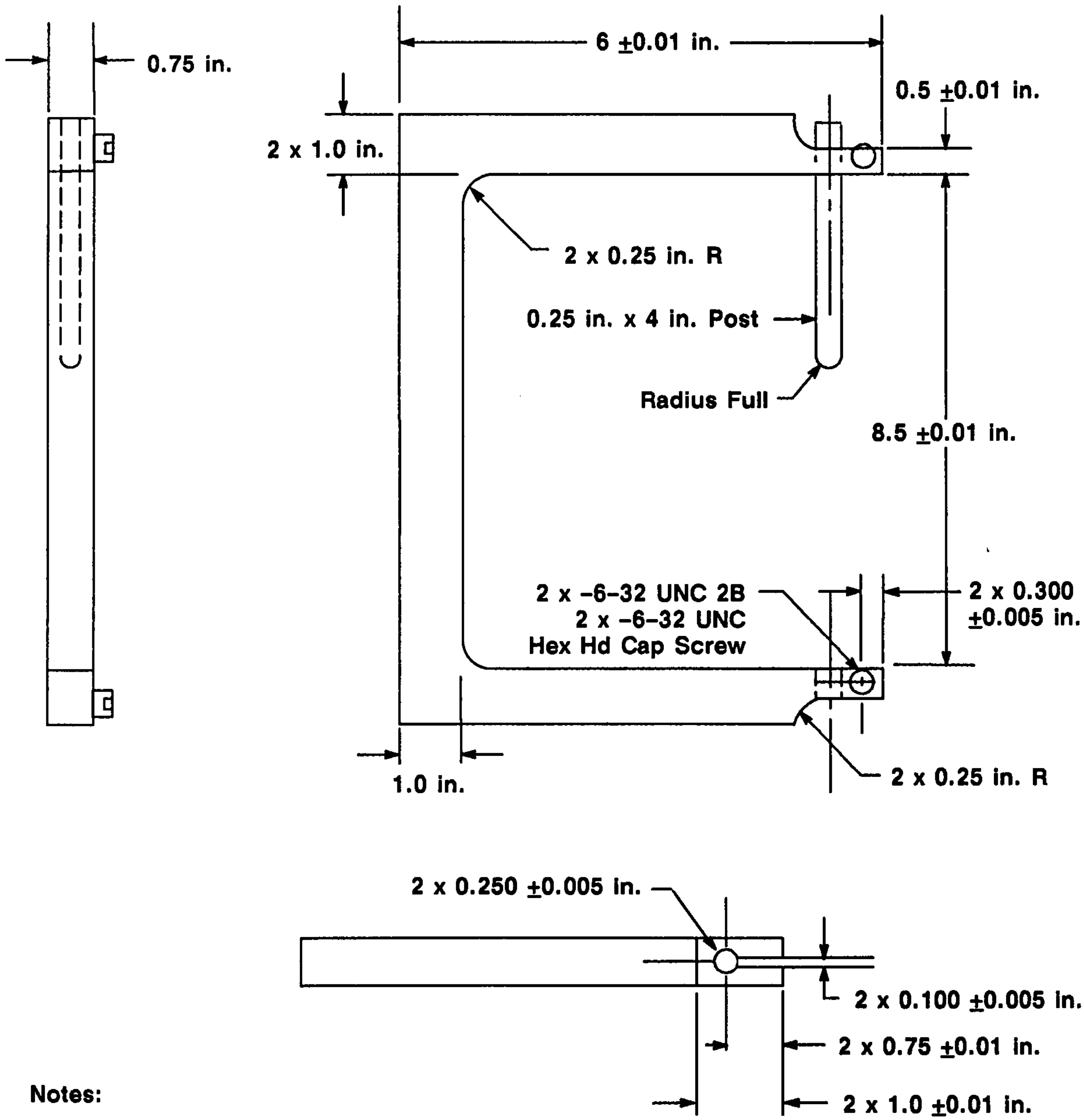


Notes:

1. Build from 1U50129 aft segment
2. Base material: Mild steel

Drawing SA10002: Threaded 8-Hole Aft Dome Fixture

A020975a



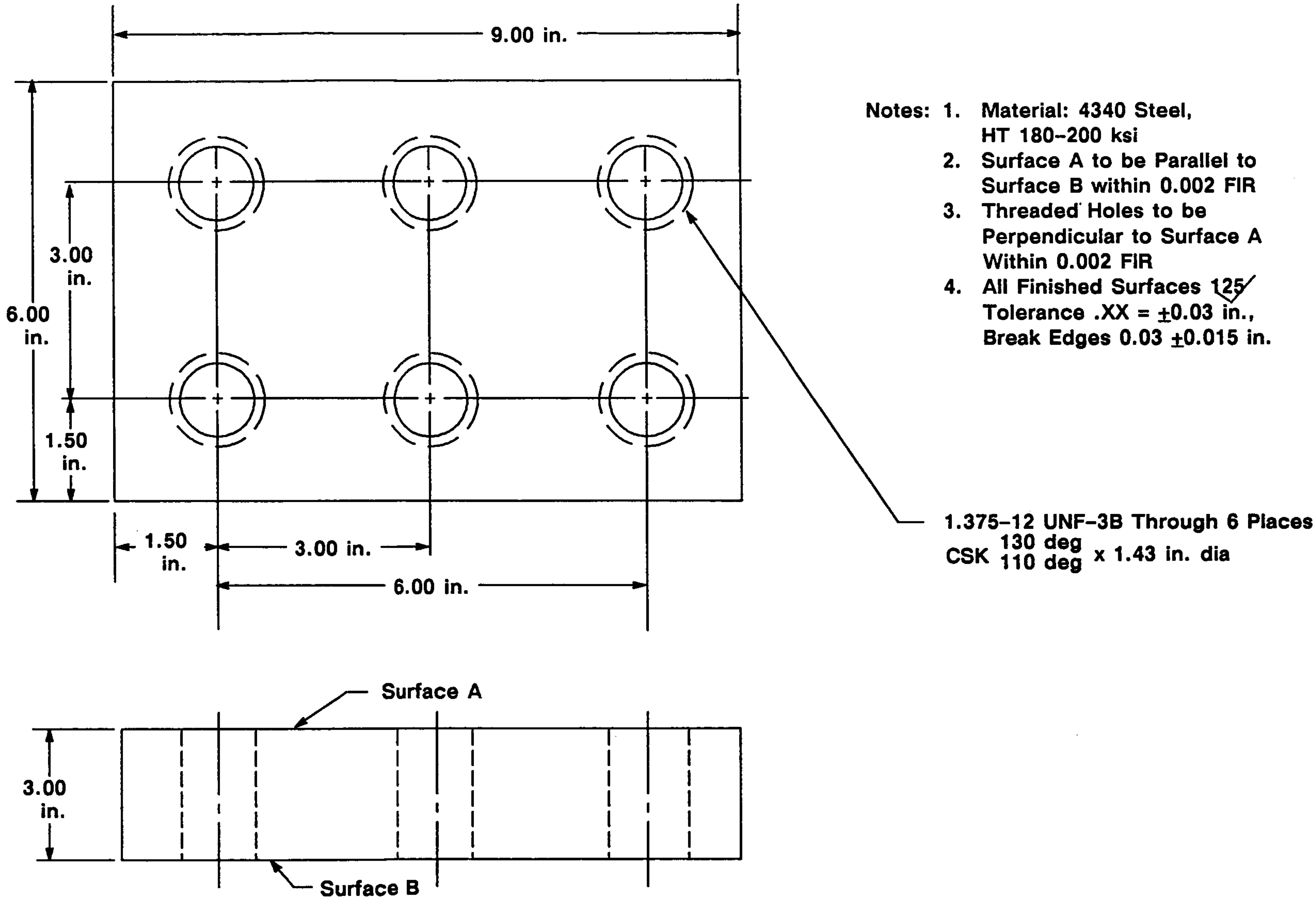
Notes:

1. Materials: C Fixture – Aluminum
   Post – Mild steel

2. Break all sharp edges

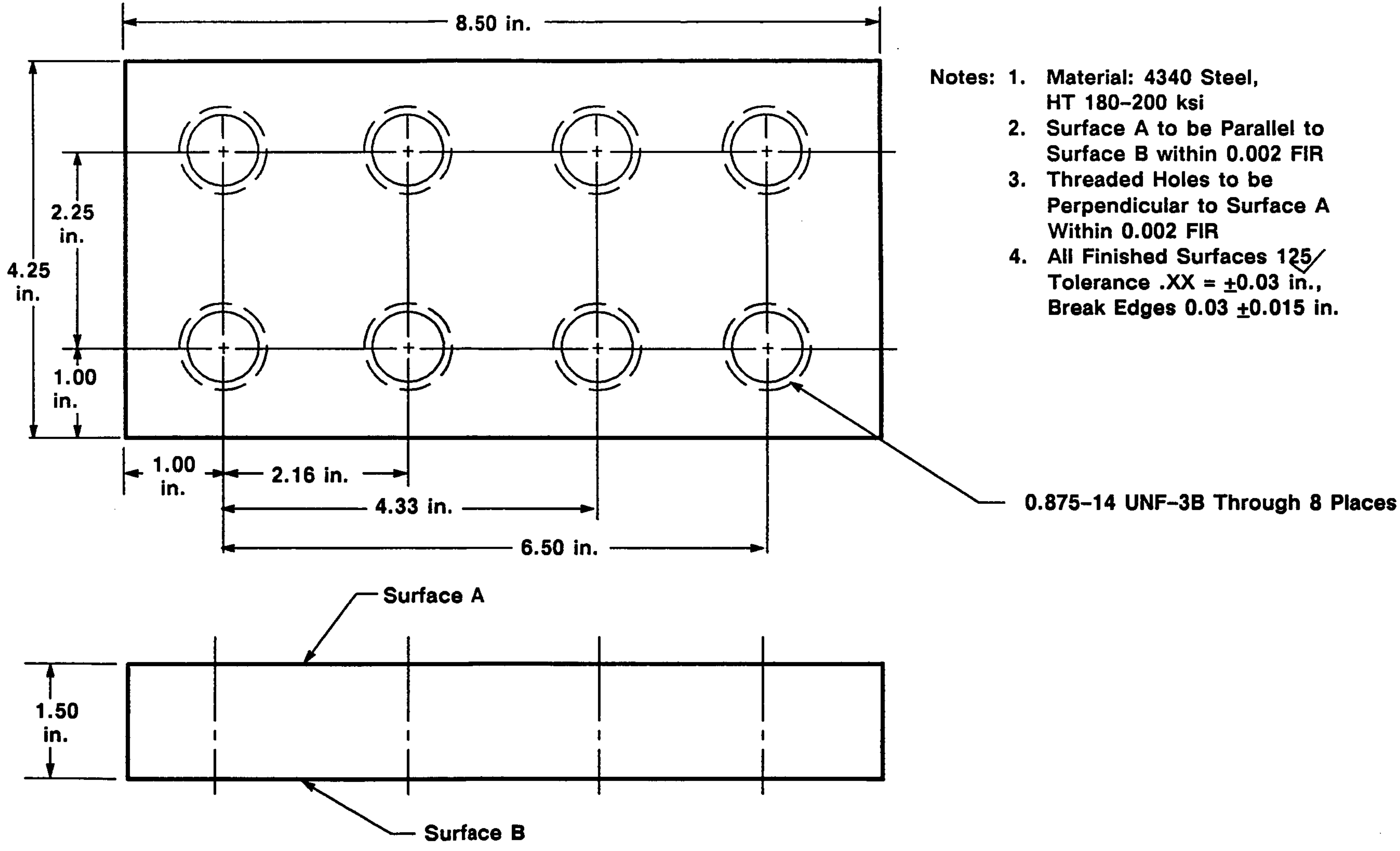
Drawing SA 10003: C-Fixture Assembly to Mount Micrometer and Steel Post

A020976a



Drawing SA 10004: 1.375-in. Axial Bolt Threaded Hole Plate

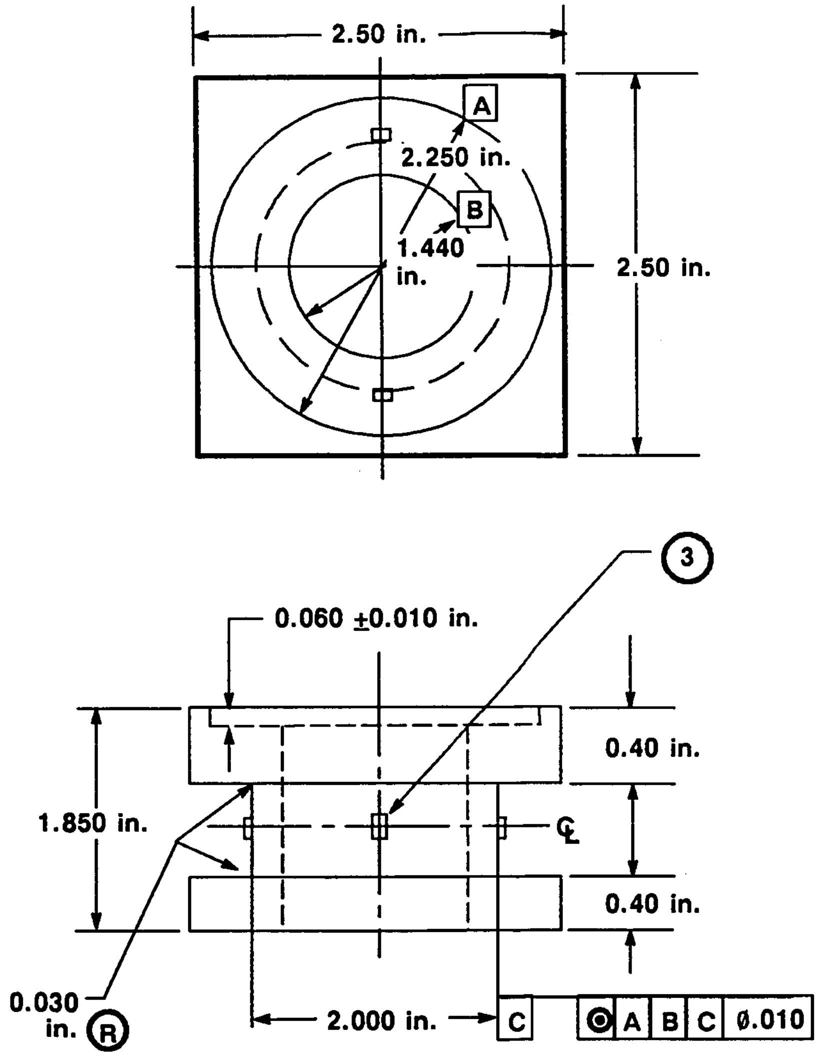
A020977a



Notes:
1. Material: 4340 Steel, HT 180-200 ksi
2. Surface A to be Parallel to Surface B within 0.002 FIR
3. Threaded Holes to be Perpendicular to Surface A Within 0.002 FIR
4. All Finished Surfaces 125 Tolerance .XX = ±0.03 in., Break Edges 0.03 ±0.015 in.

Drawing SA 10005: 0.875-in. Cross Bolt Threaded Hole Plate

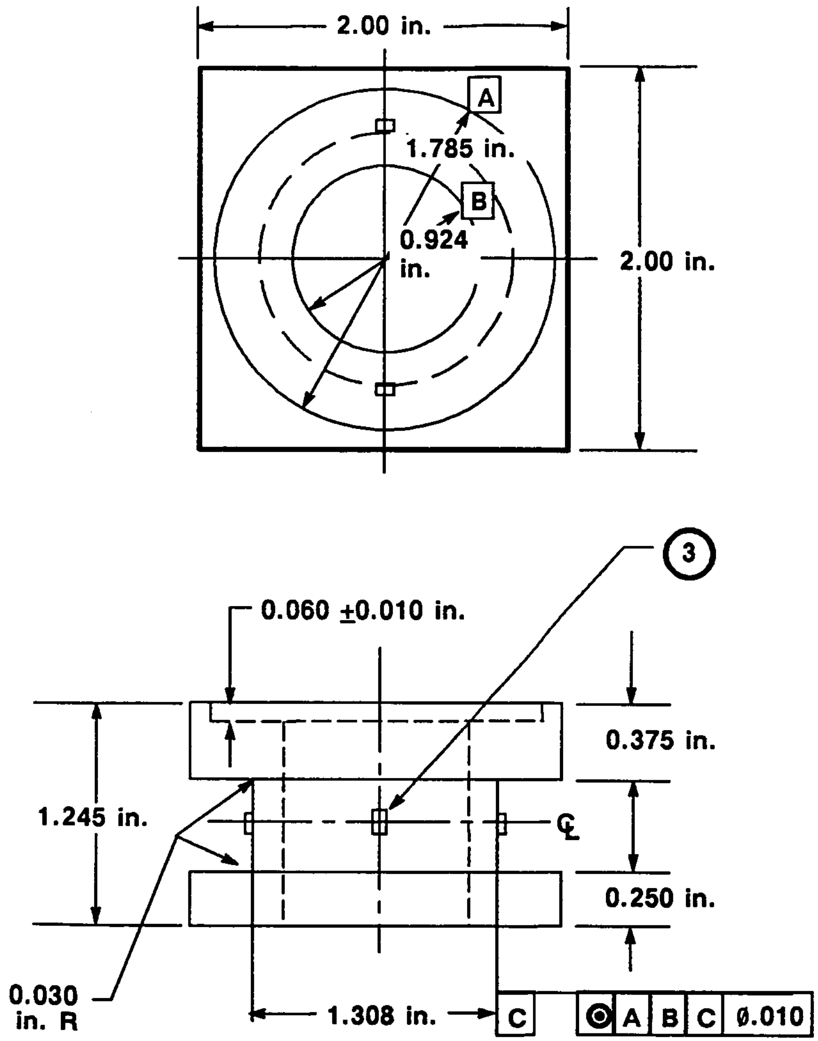
A020978a



Notes:
1. Material: AISI 4340 Steel,
2. Heat Treat Per MIL-H-6875 to 180-200 ksi
3. Strain gages (4 places) furnished and installed by Morton Thiokol
4. All Finished Surfaces 125

Drawing SA 10006: 1.375-in. diameter Load Collar

A020979a

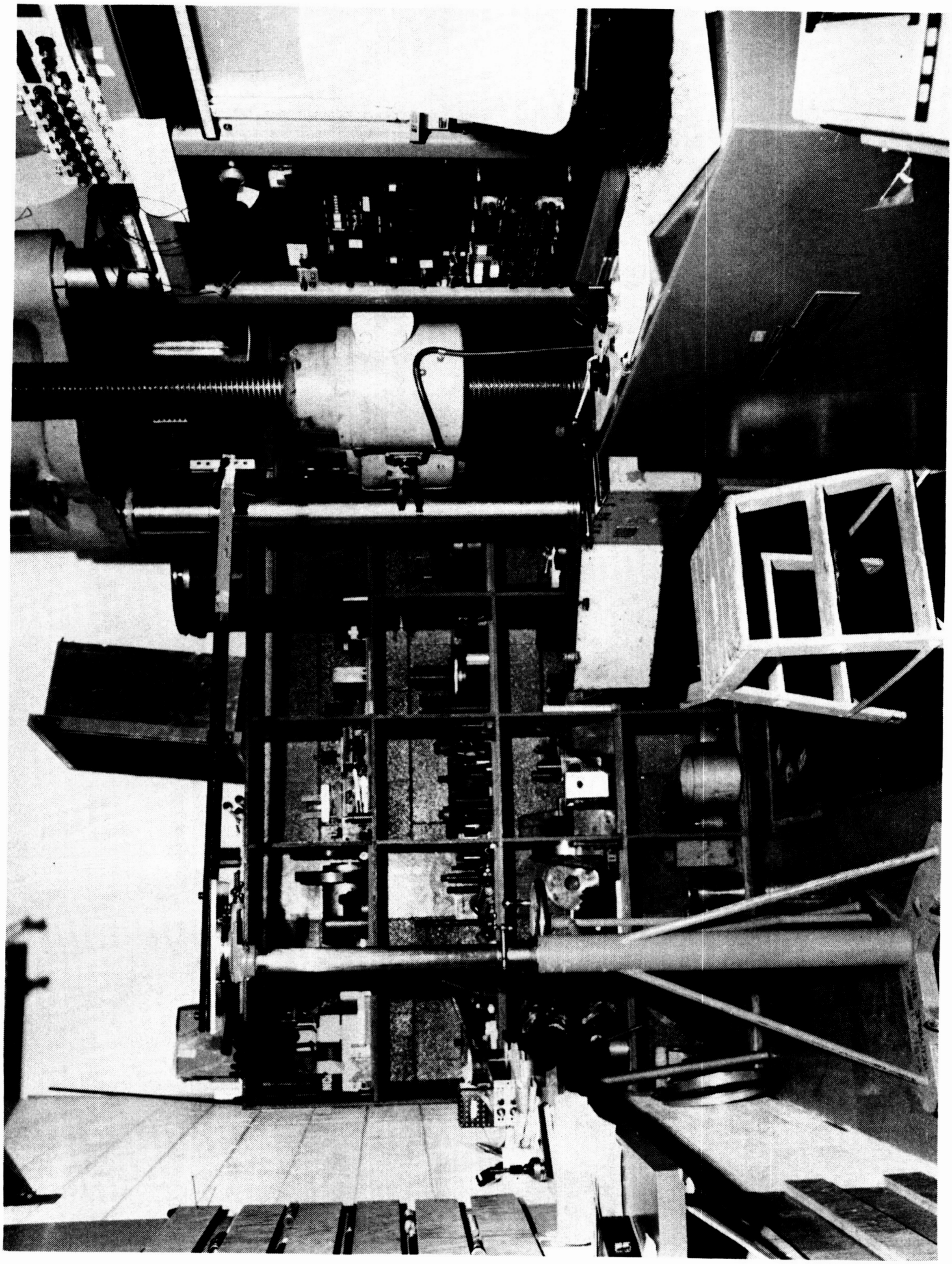


Notes:
1. Material: AISI 4340 Steel,
2. Heat Treat Per MIL-H-6875 to 180-200 ksi
3. Strain gages (4 places) furnished and installed by Morton Thiokol
4. All Finished Surfaces 125√

Drawing SA 10007: 0.875-in. diameter Load Collar

A020980a

N102969-1



Heavy-Duty Photography Stand and Crossbeam

DISTRIBUTION

Recipient	Mail Stop	Copies
D. Garecht	L36	4
S. Smith	882	1
M. Martersteck	882	1
H. Reed	882	1
J. Miles	L10	1
K. Sperry	L22	1
D. Sylte	E14	1
N. Black	L36	1
M. Williams	L36	1
C. Johnson	L31	1
D. Barraclough	881	1
K. Sanofsky	851	1
S. Rodgers	851	1
F. Duersch	851	1
T. Suatengco	L10	1
R. Jensen	L36	1
B. Snyder	L22	1
G. Cleveland	882	1
R. Papasian	E05	45
Print Crib	K23B	5
Data Management	L23E	5